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ANORTHOSITE AND RELATED ROCKS ALONG THE SAN ANDREAS FAULT SOUTHERN CALIFORNIA

BY

JOHN C. CROWELL and JOHN W. R. WALKER

UNIVERSITY OF CALIFORNIA PRESS
BERKELEY AND LOS ANGELES
1962

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University of California Publications in Geological Sciences
Editors (Los Angeles): W. C. Putnam, D. I. Axelrod, Cordell Durrell

Volume 40, No. 4, pp. 219–288, 8 plates, 4 figures in text, 2 maps

Submitted by editors November 14, 1961
Issued November 8, 1962
Price, $1.75

University of California Press
Berkeley and Los Angeles
California

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Cambridge University Press
London, England

PRINTED IN THE UNITED STATES OF AMERICA

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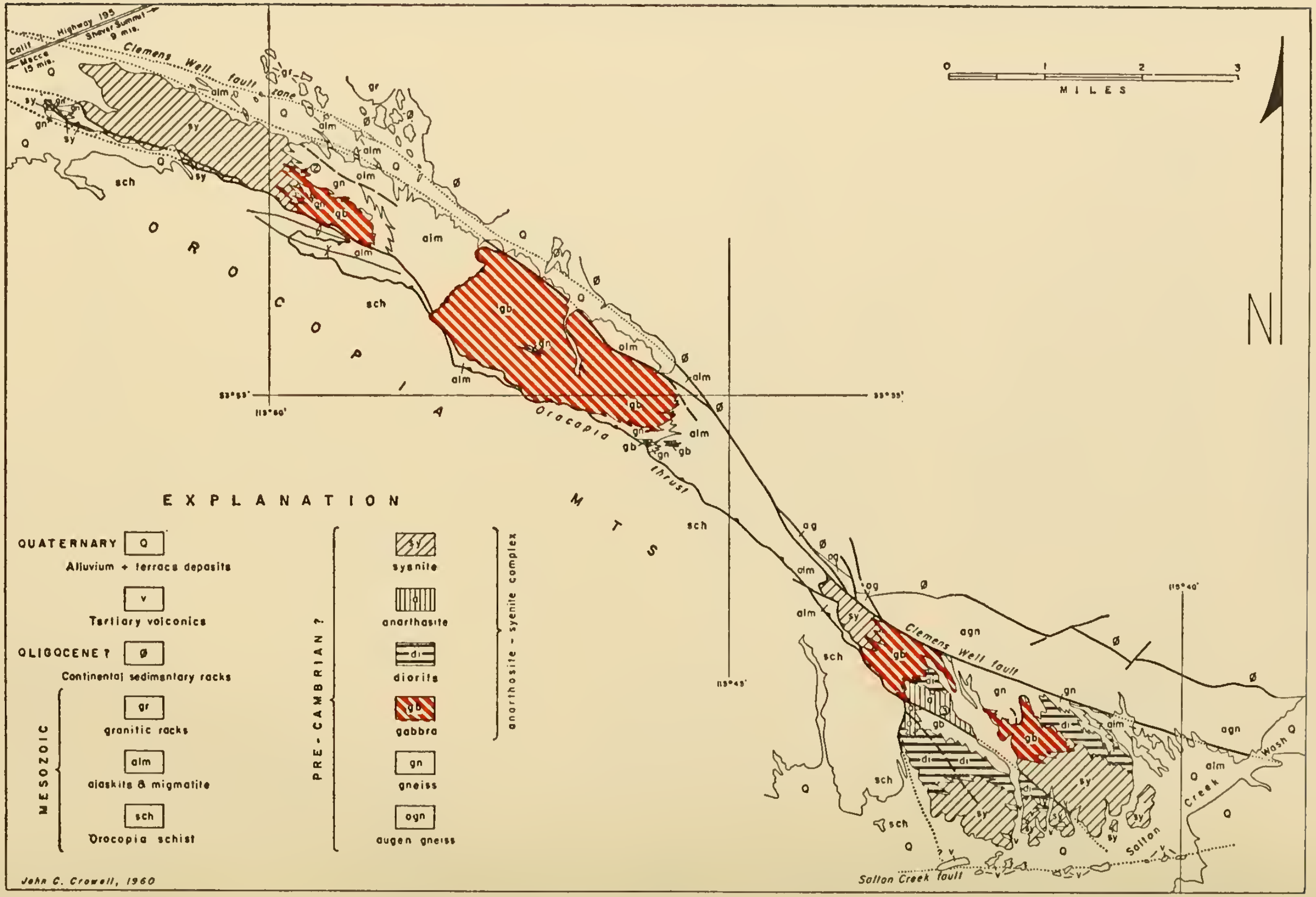

Map. 1. Geologic map of central Orocopia Mountains, southeastern California (fig. 1). Circled numbers refer to photograph localities.

ANORTHOSITE AND RELATED ROCKS ALONG THE SAN ANDREAS FAULT, SOUTHERN CALIFORNIA

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ABSTRACT

Gabbro, diorite, anorthosite, syenite, and related rocks, probably Precambrian in age, are exposed in the Orocopia Mountains near the Salton Sea, and in the San Gabriel Mountains north of Los Angeles. In both areas they intrude gneiss of the amphibolite facies. Gabbro and diorite, the most abundant rocks, are intergradational and contain hornblende and biotite after pyroxene, although original pyroxene and olivine are preserved only in the San Gabriel rocks. Plagioclase in the anorthosite ranges in composition from An_{20} to An_{45}. In each area, mafic bodies composed notably of titaniferous magnetite, ilmenite, and apatite are common. In addition, in both regions, syenite, intergrading with gabbro and diorite, is characterized by distinctive microperthite. Closely associated with the syenite are quartz-bearing syenite, alkali granite, granophyre, and pegmatite. All of these rocks were metamorphosed at least to the amphibolite facies and were intruded by granitic rocks (probably Mesozoic) and by Tertiary volcanic rocks.

The marked similarities in the petrography and field relations of the two occurrences lend support to the hypothesis that they were part of the same terrane, in the geologic past, and have now been separated by right slip on the San Andreas fault system. The San Gabriel rocks lie near the fault on the southwest side, and 130 miles from the Orocopia rocks on the opposite side. Some small exposures about 12 miles east of the San Gabriel mass, however, are in an anomalous position. Final appraisal of this hypothesis of great strike slip must await future work on other rocks in the vicinity of the fault, and a greater understanding of geologic histories of the two terranes and of the intervening country.

INTRODUCTION

WITHIN the basement complex of the Transverse Ranges of southern California, among the oldest rocks at the western continental margin of North America, are two gneissic terranes intruded by gabbro, anorthosite, syenite, and related rocks, one of which is in the San Gabriel and the other in the Orocopia mountains (fig. 1). The San Gabriel anorthosite and related rocks, previously well known through reports by W. J. Miller (1934), Oakeshott (1937; 1954; 1958), Higgs (1954), Jahns and Muehlberger (1954), Muehlberger (1958), and Dibblee (1960a; 1961), have been reëxamined for the present study.

The Orocopia exposures were discovered a few years ago by Crowell, during reconnaissance of basement terrane along the San Andreas fault. Upon discovery, the question arose whether or not they were related to the San Gabriel rocks already known. Were the Orocopia rocks an independent complex, unrelated to intrusions of similar general character in the San Gabriel Range, or were they parts of the same complex but displaced by large strike slip on the San Andreas fault? The primary purpose of this paper is therefore to place on record a description of the anorthosite, syenite, and related rocks in the Orocopia regions, and to compare them with the exposures in the San Gabriel Mountains–Soledad Pass region. The location of these exposures, as well as others referred to below, is shown in figure 1.

We believe it likely that the two terranes were once continuous (Crowell, 1960; 1962), but in order not to prejudice the case, the following two descriptions have been prepared independently of each other. They are herein kept separate, so that the reader may make an objective appraisal of the similarities and differences between the two suites of rocks and their histories. It is concluded that the comparison of the two terranes, which follows the descriptions, supports the hypothesis that they were displaced for some 130 miles on the San Andreas fault. The present report, however, describes only one part of the planned research that will investigate the displacement and history of the San Andreas fault. Other rocks in the two areas are under study, such as the augen gneisses, greenschists, Eocene strata (Crowell and Susuki, 1959), and so on. When these and other studies are completed, and when considerably more is known about the rocks and their histories all along the fault, as well as about those rocks occurring as slices within the zone, we may be able to appraise the hypothesis with confidence.

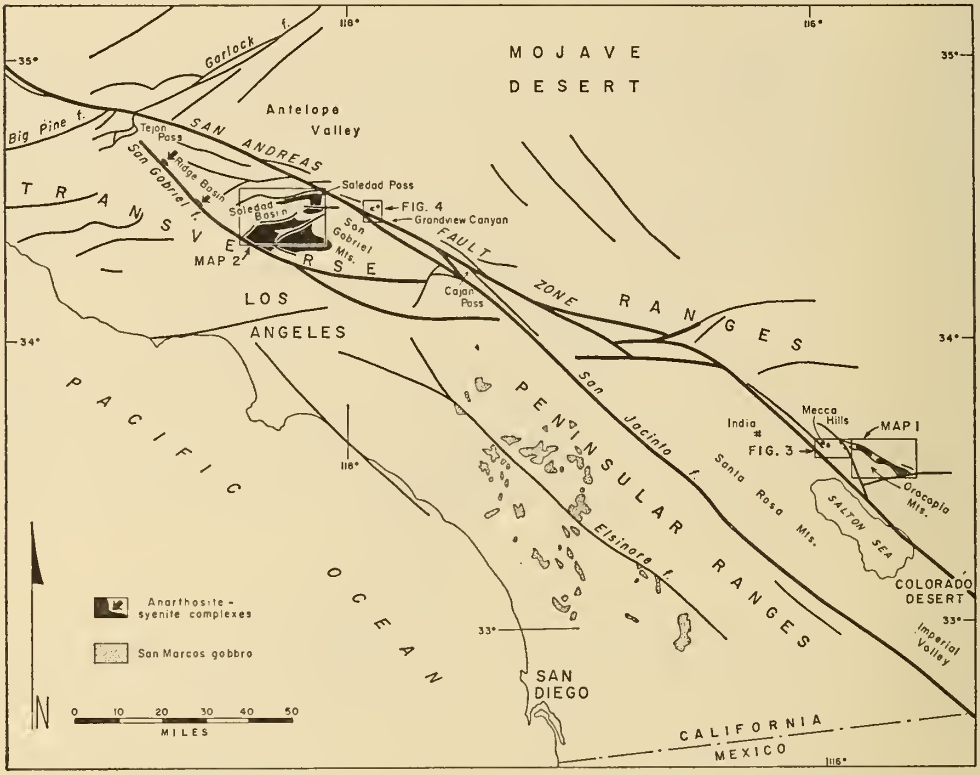


Fig. 1. Location map of areas under study and some major faults in southern California. Outcrops of the anorthosite-syenite complexes are shown in black, and the San Marcos gabbro by stippling.

Because relationships among the various rocks in each region are complex, we here present a summary, including some conclusions, as a guide to the reader. In each of the two areas, the rocks described fall naturally into five groups, which are shown diagrammatically on figure 2 and are listed here in order of their age, the oldest first:

1. Gneiss.

2. Anorthosite group, consisting of gabbro, diorite, transition rock between gabbro and diorite on the one hand, and gabbro and anorthosite on the other, anorthosite, mafic bodies, and basic dikes.

3. Syenite group, consisting of syenite, quartz-bearing syenite, alkali granite, granophyre, and pegmatite, in most of which the quartz is blue or violet in color.

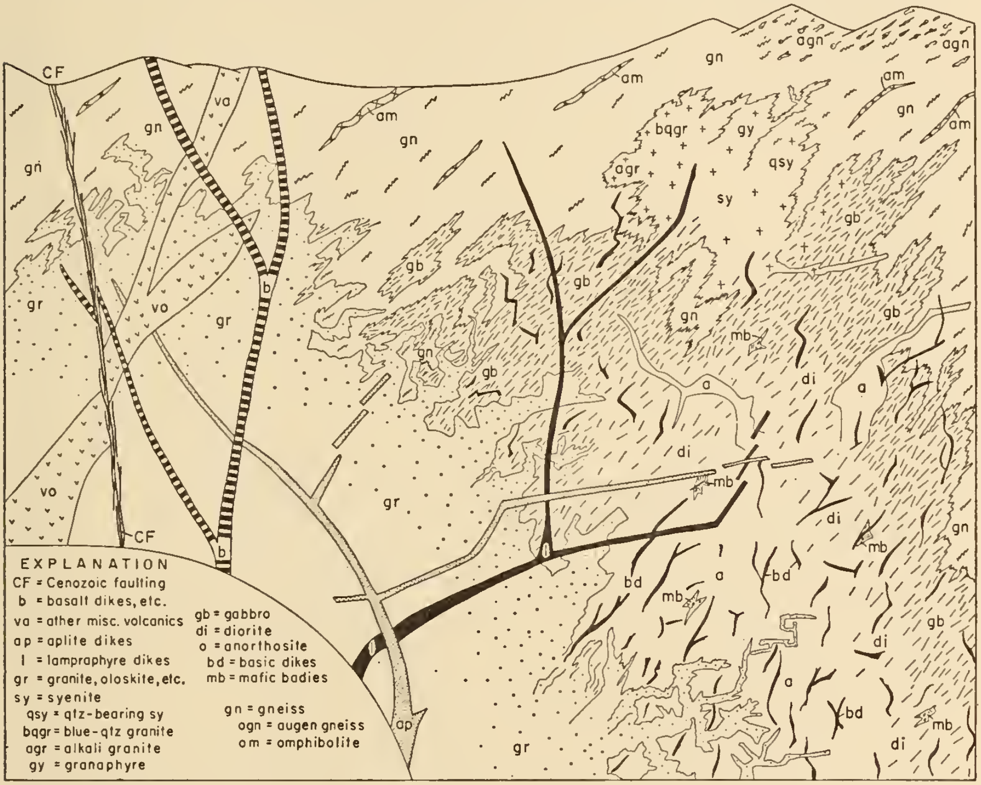


Fig. 2. Diagrammatic cross section showing relationships of principal rock types in Orocopia and San Gabriel mountains. Not to scale.

4. Granitic rocks variously referred to as granite, quartz monzonite, and alaskite.

5. Other rocks, along with associated migmatites, and consisting of volcanic and hypabyssal dikes and irregular intrusives of several kinds, probably emplaced during the Mesozoic and Cenozoic, and not dealt with here in detail.

The anorthosite and syenite groups are intimately related in both areas, and are therefore believed to be related in origin; hence they are considered as the anorthosite-syenite complex. Acccording to radiometric measurements, the anorthosite in the San Gabriel Mountains is Precambrian in age (Neuerburg and Gottfried, 1954; Silver *et al.*, 1960), but there is no independent data to confirm the age of the anorthosite in the Orocopia Mountains. Rocks of the anorthosite-syenite complex of the San Gabriels are therefore treated as Precambrian, and those of the Orocopias as Precambrian (?). In both regions gneiss, which was already metamorphosed at the time of the emplacement of the anorthosite-syenite complex, has been at places migmatized and reconstituted during the intrusion of the complex. Both the gneiss and the complex were later regionally metamorphosed, probably in connection with events culminating in the emplacement of granite. These granitic rocks are considered as Mesozoic (?) in age because of their similarity to plutonic rocks of the Peninsular Ranges, Sierra Nevada, and others (Larsen, 1954; Curtis *et al.*, 1958). Locally they form veins, dikes, and irregular bodies, including migmatites, with rocks of the gneiss and anorthosite-syenite complex. Where migmatites, which were originally formed between anorthosite-syenite complex and gneiss, have been migmatized and veined again by granite, the relations are especially complicated and the original identity of many rocks cannot be established.

The rocks in both areas are intensely shattered, brecciated, granulated, and altered. Shattering occurred within the anorthosite-syenite complex during or just after its emplacement in the Precambrian(?). Hydrothermal alteration, accompanied by carbonate deposition and some shearing and brecciation, was associated with the intrusion of later volcanic and hypabyssal rocks. Breccia zones (including microbreccias, mylonites, and cataclasites), faults (major and minor), and joints resulted from repeated tectonic deformation throughout the Cenozoic. Although both intrusive and structural events have joined to obscure the histories of the terranes, these histories are nevertheless decipherable. Because they are so complex, however, the sequence of events aids significantly in attempting to correlate the terranes in the two now-distant areas. Not only must the petrology of the two areas correspond, but the geologic histories of the old rocks must also correlate, if we are to accept the hypothesis of great displacement on the San Andreas fault. Throughout this research, therefore, the emphasis has been placed on acquiring petrographic and historical information which can be used in correlation. Many petrogenetic problems have been uncovered and are referred to, but their solution will have to await study by future workers.

The research described here has been partly supported by grants from the Institute of Geophysics, the Department of Geology, and the Committee on Research, University of California, Los Angeles. We are grateful, as well, to Professor Cordell Durrell for critical comments on the manuscript.

OROCOPIA AREA

The Orocopia Mountains lie north and northeast of the Salton Sea, in southeastern California, and decrease in height from a maximum of 3,815 feet toward the northwest into the flanking Mecca Hills. Spurs extend southward to elevations at sea level near the Salton Sea, with a surface elevation of 235 feet below sea level in 1958. The Coachella Irrigation Canal, which brings water from the Colorado River near the Mexican border to the vicinity of Indio, outlines the base of the Orocopia Mountains and Mecca Hills. The southern part of the area is therefore most easily reached from the road along the canal and from the few unimproved roads that extend northward into canyons from it. The only paved highway through the Mecca Hills is the Box Canyon road (California State Highway 195) which connects California State Highway 111 with the transcontinental U.S. Highway 60 and 70 on the north (fig. 3). The most extensive and accessible exposures of the anorthosite and related rocks are those north of Salton Creek Wash (map 1) and can be reached on foot from a standard automobile parked along the sandy road in Salton Creek Wash (pl. 2, *a*). Typical exposures, though not extensive, are also found in the upper reaches of Painted Canyon, about one mile north from the improved parking area, and are those exposures most easily reached on a short visit (fig. 2). The very dry climate characteristic of the region is responsible for excellent outcrops, particularly in steep, narrow canyons, but the desert weathering imparts a brownish hue to all basement rocks, so that they can be identified only at close range. On the whole, the region is rugged, and some canyons are impassable for a man working alone and on foot.

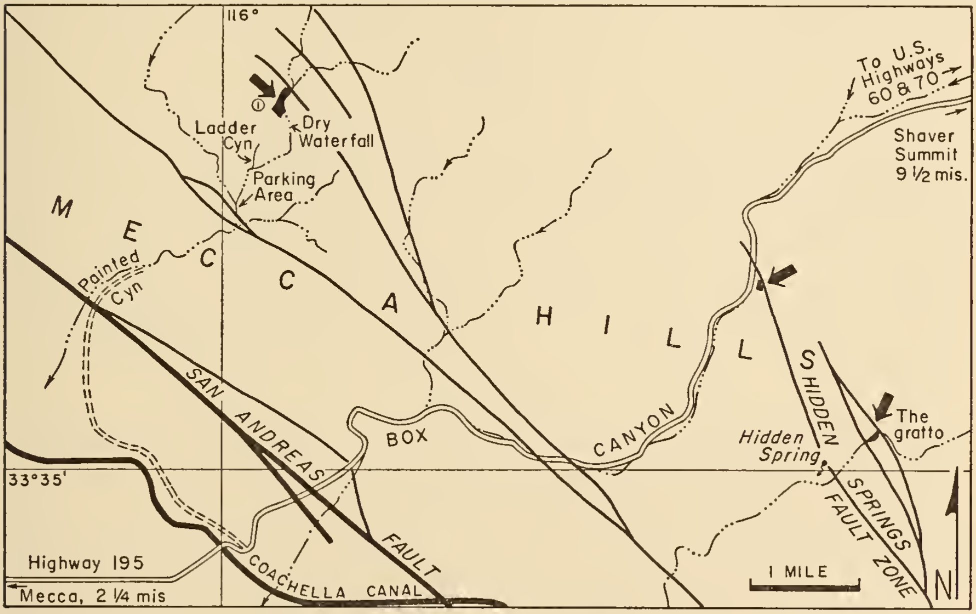


Fig. 3. Sketch map showing location of small exposures of anorthosite and related rocks in the Mecca Hills, north of the Salton Sea. Figure 1 outlines the location of this map. The trace of the faults in the vicinity of Box Canyon is after W. H. Hays (1957); the fault pattern in Painted Canyon and along the Hidden Springs fault zone is by Crowell. Circled numbers refer to photograph localities.

The Orocopia Mountains consist of a high-standing core of Orocopia Schist (Miller, W. J., 1944), flanked on the north and northeast by a deformed fault wedge of gneiss, and rocks of the anorthosite-syenite complex, which are in turn intruded by Mesozoic (?) granitic and Cenozoic volcanic rocks (map 1). This elongate wedge containing most of the rocks of the anorthosite-syenite complex is bounded on the southwest by the Orocopia thrust, which is at places tightly folded. The wedge has a maximum width of about two miles, near Salton Creek Wash, and is bordered on the northeast by the near-vertical Clemens Well fault zone. Augen gneiss and migmatite are present across the Clemens Well fault at the southeast, granitic rocks at the northwest, and deformed Oligocene (?) beds with volcanics between them. The gneiss associated with the anorthosite–syenite complex is very different from the augen gneiss on the northwest side of the fault, and there is as yet no way to relate them.

In the Mecca Hills the anorthosite and related rocks are exposed in three small areas (fig. 3). The best outcrops are in vertical cliffs of upper Painted Canyon in the SE¼ sec. 24, T. 6 S., R. 9 E. (pls. 1, *a*, *b;* 2, *b*). Near Hidden Spring, a small outcrop of anorthositic diorite, lies in the bottom of "The Grotto" (SW¼ sec. 1, T. 7 S., R. 10 E.) and also within the Hidden Springs fault zone near the center of sec. 35, T. 6 S., R. 10 E.

Gneiss

The oldest rock, gneiss, occurs as intermittent bordering shells around the anorthosite-syenite complex and also as isolated inclusions and septa within the complex. These gneissic bodies range from a few feet to several hundred feet across and are especially well exposed in the regions where the gneiss is delineated on the map (map 1), although smaller bodies occur at many other places. The gneiss is cut by the anorthosite-syenite complex and by later granitic bodies (pl. 1, *b*). Foliation within it generally dips steeply, and at many localities the contact with the anorthosite-syenite complex is gradational; at others it cuts sharply across the layering.

PETROGRAPHY

The gneiss consists of interlayered leucogneiss, mafic gneiss, and amphibolite, in which the layers range in thickness from less than an inch to several feet. Leucogneiss prevails where the rock is rich in granoblastic mosaics of quartz and feldspar, and mafic gneiss where nematoblastic hornblende and lepidoblastic biotite predominate. The quartz is characteristically blue or violet in color, and at places it comprises entire small lenses. The amphibolite, which is gradationally interlayered with mafic gneiss, consists of dark green or greenish-black massive rock. Near contacts with gabbro, white plagioclase set in a background of ferromagnesian minerals imparts a mottled dioritic appearance. Some of the gneiss is mylonitic, with thin lenses of blue quartz and feldspar.

Relative proportions of the constituent minerals in this gradational sequence vary considerably. Hornblende forms up to 50 per cent of the amphibolite, with about 40 per cent oligoclase-andesine, 5 per cent quartz, and the remainder accessory sphene, black oxides, and apatite. Such rocks form about 15 per cent of the gneiss and are interlayered with the lighter-colored gneiss. Typical intermediate gneiss contains 25 per cent plagioclase (oligoclase, An_{10-30}), 20 per cent potash feldspar, 30 per cent quartz, 5 to 10 per cent biotite, 15 per cent hornblende, and up to 5 per cent of apatite, sphene, black oxides and zircon. The quartz content of gneiss containing layers of nearly pure blue quartz is as high as 50 per cent.

Quartz.—The quartz is highly strained and contains numerous dusty inclusions which probably account for its blue color in hand specimen. Quartz, in some of the quartz-rich gneisses, occurs as globular masses which embay and penetrate the feldspars. Mosaics of quartz grains also occur in micro-augen oriented parallel to foliation.

Plagioclase.—The plagioclase is commonly xenoblastic, clear, with well-defined twin lamellae. It is oligoclase (An_{10-30}) in the leucogneiss and oligoclase or calcic andesine in the mafic gneiss. Where regression or hydrothermal alteration of the gneiss has taken place, the plagioclase is partially saussuritized and clouded with fine-grained white mica.

Potash feldspar.—The potash feldspar is predominantly microcline, but there is minor untwinned orthoclase and occasional microperthite. Some of the microperthite is similar to the exsolution type in the syenite. The unmixing texture here would seem to have a metamorphic origin, inasmuch as it occurs in gneiss. The potash feldspar is xenoblastic and generally fresh, but sericitized where the rocks have undergone regression.

Biotite.—Biotite, with x = pale yellow, y + z = brown, is largely regressed to penninite. It is subordinate in the hornblende-rich rocks, but exceeds hornblende in the leucogneiss, especially where potash feldspar is abundant. In the leucogneiss, thin schistose layers consisting of lepidoblastic biotite, of biotite and hornblende, or of pure hornblende separate the quartzo-feldspathic layers and suggest original shaly laminae of different compositions.

Hornblende.—Hornblende, with x = pale yellow-green, y = light green, z = bluish-green to brownish-green, occurs in the amphibolites as meshlike aggregates of blocky subidioblastic prisms having a generally preferred orientation. Some prisms are poikiloblastic with inclusions of plagioclase, quartz or sphene.

Accessory minerals.—Irregular, sievelike aggregates of sphene, abundant subhedral apatite, scattered subhedral magnetite, occasional rounded zircon, and a few tiny red garnets (less than 0.5 millimeters across) comprise the accessory minerals. A few small grains and porphyroblasts of epidote are present, particularly in the amphibolites.

ORIGIN AND HISTORY

The gneiss has now attained the amphibolite facies of regional metamorphism, as shown by the mineral assemblage hornblende–oligoclase–(epidote)–sphene–quartz–biotite in the dark gneiss. The quartzo-feldspathic gneiss interlayered with the dark gneiss has no doubt also arrived at the amphibolite facies.

Amphibolite, rich in hornblende and with dioritic texture, could have been derived from either basic volcanic flows or older basic intrusives. The intermediate quartzo-feldspathic gneiss, especially that with very thin layering, could have come from intermediate tuffs or siltstones. The gneiss high in quartz could have been sandstones. Assemblages such as:

Quartz–microcline–plagioclase–biotite–hornblende
Oligoclase–orthoclase–quartz–hornblende–biotite
Quartz–garnet–hornblende–biotite–oligoclase

correspond to rocks high in the amphibolite facies.

The gneiss is probably polymetamorphic and may have undergone at least two regional metamorphisms: (1) A Precambrian(?) metamorphism before the intrusion of the anorthosite–syenite complex, followed by attendant contact metamorphic effects, and (2) Mesozoic(?) metamorphism which culminated with the emplacement of the granitic plutons. Only locally has the Mesozoic(?) regional metamorphism obliterated the effects of earlier metamorphism. Mylonitization was fairly widespread, following the earlier metamorphism, although some cataclasis is probably associated with Cenozoic faulting. Later regressive metamorphism is difficult to distinguish from some of the hydrothermal alteration. Further comparison of structures in the gneiss with those in the anorthosite-syenite complex might reveal information about an earlier metamorphism, but such an investigation has not been undertaken for this study.

Anorthosite Group

The anorthosite group includes the following rock types, listed with the youngest first, all of which have undergone regional metamorphism:

1. Basic dikes.
2. Mafic bodies.
3. Anorthosite.
4. Gabbro and diorite; "dappled" rock transitional to anorthosite; minor quartz diorite dikes and masses.

The group comprises areally about one-sixth of the exposed rocks in the wedge between the Orocopia thrust and the Clemens Well fault. Most of this is gabbro and diorite, although anorthosite predominates in Painted Canyon and in some areas north of Salton Creek Wash.

The intrusion of the anorthosite group into gneiss is shown by several features:

1. Septa and inclusions of gneiss are present in gabbro, diorite, and anorthosite.
2. Dikes and irregular bodies of gabbro, diorite or anorthosite cut gneiss, and migmatite.
3. Dioritic layers occur parallel to foliation in the gneiss and may possibly be older amphibolite layers, but they are petrographically similar to the gabbro. At several places the textural and mineralogical features, such as coarse purplish plagioclase interstitially within roughly tabular hornblende, are so similar that the correlation seems almost certain, and the material of the layers is therefore considered to be largely injected (pl. 1, *b*). These rocks are most abundant near contacts with gabbro; they do not resemble closely the finer-grained amphibolite of the gneiss, although locally they cannot be distinguished.
4. Probable assimilation of portions of the gneiss is indicated by irregular "dioritized" patches that grade into both diorite and gneiss.

Much of the gabbro and diorite has a discontinuous and indistinct foliation and lineation, which may be due both to primary magmatic flow and to metamorphism, but the rocks have not been studied sufficiently to determine which. Alternating layers of plagioclase and dark minerals up to a foot in thickness are common. Such layered portions of the gabbro and diorite are discontinuous, and attitudes of the layers are variable and do not necessarily conform to layering in the gneiss. Local zones of brecciation and shearing which cross-cut the layers are present throughout the gabbro and diorite.

Gabbro and diorite intergrade with a rock transitional to anorthosite. Anorthosite occurs as lenticular bodies, at places as large as 250 feet long and 20 feet wide, within gabbro, diorite, or the transitional rock. Contacts of the anorthosite with gabbro and diorite are commonly sharp, but with the transitional rock they are generally gradational. Shearing occurred in rocks adjacent to the contacts of many anorthosite bodies, perhaps in part during their emplacement and in part during Cenozoic deformation.

Anorthosite occurs also in larger masses which crop out over several thousand square feet, in Painted Canyon and north of Salton Creek Wash. These masses contain subordinate dioritic and mafic phases and grade into transitional rock.

Irregular mafic bodies occur in the gabbro and diorite, but they are more common in the transitional rock and anorthosite. They are lenticular or veinlike bodies and have evidently filled late fractures in the anorthosite complex. In composition, the rocks consist of ilmenite and magnetite, with varying amounts of apatite and ferromagnesian minerals. Because shears are conspicuous, along contacts of the large mafic bodies with gabbro, diorite, or anorthosite, the shearing appears to be related to their emplacement, although some may have accompanied Cenozoic faulting. Several large bodies of ilmenite–magnetite–apatite rock northwest of Salton Creek Wash have been prospected, but as yet none has been mined.

Numerous basic dikes, ranging in width from a few inches to four feet, cross-cut the anorthosite group and gneiss. They are metamorphosed, in places sheared, and are late intrusions in the anorthosite group, to judge from their composition and texture. Hypautomorphic intergrowths of feldspar and amphibole, with some lamprophyric centers, have been recognied. These basic dikes, which clearly transect the anorthosite and are themselves foliated, provide evidence for the metamorphism of the group. As a rule, they are considerably more altered, deformed, and foliated than younger lamprophyric and diabasic dikes of probable Mesozoic and Cenozoic age, although locally the several types of dikes cannot always be distinguished.

PETROGRAPHY

Gabbro, Diorite, and Transitional Rock

The separation of gabbro and diorite into two lithologic units on the map (map 1) is based only on field identification and color index. Rocks containing plagioclase and more than 50 per cent ferromagnesian minerals were mapped as gabbro. On the basis of the plagioclase composition, the bulk of both gabbro and diorite is diorite. The transitional rock which commonly occurs between the anorthosite and the gabbro and diorite is essentially a leucodiorite and is not shown as a separate unit on the map.

The gabbro and diorite range greatly in texture and composition. They are fine- to extremely coarse-grained, some of the diorite containing hornblende crystals exceeding a foot in length. Plagioclase crystals up to six inches long occur in the transitional rock. The gabbro and diorite are mottled greenish- or brownish-black. The transitional rock has a dappled appearance, due to scattered, semialigned clots of ferromagnesian minerals. Textures of the gabbro, diorite, and transitional rock are typically hypautomorphic, although diabasic and subophitic phases are common. Xenomorphic–granular textures are found in parts of the fine- to medium-grained gabbro.

An average mineralogical composition for both gabbro and diorite is about 45 per cent plagioclase (in some rocks partially or entirely replaced by epidote), 45 per cent ferromagnesian minerals (hornblende or biotite), and 10 per cent iron ore minerals, but there is considerable variation. Irregular patches of the transitional rock contain as much as 90 per cent plagioclase. The minor accessories include apatite, sphene, and occasional zircon. Common alteration minerals are chlorite, epidote, carbonate, talc, white mica, and quartz. In the diorite, fine-grained lenticular bodies ranging up to 6 inches wide consist almost entirely of poikiloblastic epidote. Interstitial quartz, at places blue-gray in hand specimen, amounts to as much as 15 per cent in some phases of the complex, in which case the rocks are quartz diorite.

Plagioclase.—The plagioclase is oligoclase-andesine (An_{28-45}) and only one specimen contains plagioclase as calcic as labradorite (An_{55-70}).

There are two types of plagioclase (pl. 3, *a*): (1) medium- to coarse-grained, relatively uniform in composition, and generally clouded with fine-grained epidote and mica; and (2) fine-grained, strongly zoned, and clear, with cores as calcic as An_{45}. The average anorthite content of the coarser-grained cloudy plagioclase is about 5 per cent less than that of the fine-grained clear variety, probably because of removal of CaO to form the epidote.

The fine-grained plagioclase occurs as a granular mosaic interstitial to, or filling fractures in, the coarse-grained plagioclase. This feature is more often seen in the rocks transitional to anorthosite than in gabbro or diorite. Some of the large plagioclase grains in the transitional rock have granulated borders, now recrystallized, and many display deformed and offset twin lamellae. Numerous fractures, both irregular and in sets, transect both types of feldspar and in general are not controlled by cleavages. Most of these fractures are probably related to the emplacement, or shortly followed it in origin, because they can be seen in relatively undeformed portions of the rock and do not appear to be associated with transecting later events such as Mesozoic (?) granitic or Cenozoic volcanic intrusions, or the Cenozoic faulting. It is possible, however, that some are related to post-consolidation shearing, brecciation, or mylonitization, especially where the feldspars are highly sericitized and fractures are filled with quartz and carbonate. It is further possible that the finer-grained plagioclase results from metamorphic reduction in grain size of what were originally coarser-grained plagioclase. Larger grains may have been decomposed to small aggregates of alteration products which have then recrystallized to form fine-grained clear plagioclase.

Hornblende.—Hornblende (with x = pale yellow, y = deep green, z = blue-green and $z \wedge c$ from 10° to 20°) is the common ferromagnesian mineral in most of the diorite. Typically, it occurs both as a mesh of crisscrossing subhedral prisms and as stubby prisms randomly intermixed with biotite flakes. Many of the coarse hornblendes are poikiloblastic and envelop irregular areas of plagioclase. Some hornblendes are charged with numerous dusty inclusions of black oxides and leucoxene, concentrated in planes parallel to prismatic cleavages and 001 partings. Other inclusions are large grains of black oxides, sphene, biotite flakes, and granules of epidote or clinozoisite. Near contacts with gneiss, and in the dioritic injections in gneiss, hornblende occurs in platy aggregates of stubby, subidioblastic prisms. Intergrown fine-grained mosaic quartz, black oxides, and sphene impart a sieve texture to these aggregates.

Biotite.—Biotite is the common ferromagnesian mineral in the rock transitional to anorthosite, and it is found also in variable amounts throughout other phases of the diorite. It is strongly pleochroic, with $x =$ yellow or pale yellow and $y + z =$ golden brown or reddish-brown, and it is extensively pseudomorphed or partially replaced by a pale-green chlorite. It occurs in clusters of randomly oriented flakes surrounding grains of black oxides and apatite, or as lepidoblastic flakes wrapping plagioclase. The latter occurrence is typical of the foliated diorite. The biotite seems to be metamorphic in origin, and in the dappled transitional rock, individual biotite clusters have rectangular or subrectangular outlines which suggest a former pyroxene, although no relict pyroxene cores have been found. Some biotite occurs marginal to, or intermixed with, hornblende. Included fine-grained mosaics of quartz impart a sieve texture to many clusters of biotite flakes.

Accessory minerals.—The black oxides consist mostly of ilmenite or titaniferous magnetite and have two principal occurrences: one as scattered fine grains resulting from the breakdown of ferromagnesian minerals, and another as irregular masses which partially enclose other minerals or occur as veinlets. Many discreet grains are subhedral to euhedral in outline, but are closely associated with the veinlike masses. Abundant subhedral to euhedral apatite crystals commonly occur as inclusions in the black oxides. Irregular masses of sphene mantle some grains of black oxides. In Painted Canyon, garnet aggregates up to several inches across occur with gneissic anorthosite.

Alteration minerals.—Epidote and clinozoisite are the common alteration products of the plagioclase. They occur either as poikiloblastic grains, which in some rocks almost completely replace the plagioclase, or as very fine-grained inclusions intermixed with sericite in the medium- to coarse-grained, weakly zoned plagioclase. The latter occurrence is probably due to late magmatic epidotization, and in the sheared rocks to hydrothermal action. The coarser poikiloblastic epidotes, however, are probably metamorphic.

Chlorite is the principal alteration product of biotite, and to some extent it is found along cleavages or around grain boundaries or hornblende. It also occurs in veinlets with black oxides and quartz. Carbonate is confined mainly to veinlets. These alteration minerals are due probably to late hydrothermal action.

Anorthosite

The anorthosite is a medium- to coarse-grained rock, white weathering and bluish-white on fresh surfaces. Numerous fractures, some of which occur in sets, transect the rock. The structure is generally massive, although where mafic minerals are conspicuous, a crude layering is evident. No lineation or foliation, except a few tiny through-going shears, are noticeable in thin sections. Textures are typically xenomorphic- to hypautomorphic-granular, although in some rocks there is interstitial fine-grained plagioclase.

The plagioclase is oligoclase–andesine, An_{20-45}, and, like that of the diorite and transitional rock, is of two types: (1) medium- to coarse-grained, weakly zoned and clouded with fine-grained micas and epidote minerals, and (2) fine-grained, strongly zoned, clear plagioclase with cores as calcic as An_{45}. Zoning in the fine-grained plagioclase is normal and tends to conform to the outline of the grains.

The coarse plagioclase is cut by many fractures filled with a mosaic of fine-grained clear andesine and minor quartz (some of which is blue), carbonate, and chlorite. Some of these veinlets stem from interstitial pockets of fine-grained clear andesine, which is white in hand specimen and contrasts with the more bluish, coarser grains. Many large grains have granulated borders and deformed or displaced twin lamellae.

The anorthosite is 95 to 99 per cent plagioclase. Epidotized phases are common, and in some rocks most of the plagioclase has been replaced by epidote or clinozoisite. Minor constituents include interstitial or veinlike ilmenite and titaniferous magnetite, euhedral apatite, occasional zircon, biotite (chloritized), quartz, and carbonate.

Mafic Bodies

The lenticular or dikelike bodies are dark green or black, and are medium-grained, with hypautomorphic and complex kelyphitic and poikiloblastic textures. The rocks are mostly massive, but in some there is primary magmatic layering, and many are gneissose or schistose. The layering is probably primary, because distinct layers, composed dominantly of black oxides and apatite, contrast sharply with layers in which ferromagnesian minerals predominate, and it is not likely that extreme metamorphic differentiations would account for this contrast.

There is great diversity in the number and relative proportions of minerals present in the mafic bodies. Typical assemblages are:

1. Massive aggregates of nearly pure ilmenite or titaniferous magnetite.
2. Hornblende–actinolite–(chloritized) biotite–epidote–talc–ilmenite–magnetite–apatite.

Euhedral apatite, poikilitically included in dark minerals, forms 25 per cent of some rocks.

The biotite is dark brown or dark red lepidomelane, and in most of the rocks it is partially or entirely pseudomorphed by pale green chlorite.

The hornblende is mostly a blue-green variety, but blocky crystals of brown hornblende containing relicts of augite were observed in one specimen. The brown hornblende has blue-green rims, and many of the augite relicts are partly changed to talc and fine-grained magnetite. Both blue-green and brown hornblende are characterized by acicular terminations. Closely associated with the hornblende, but confined mainly to distinct layers, are stubby prisms of actinolite. The actinolite, and possibly cummingtonite, also forms irregular rims around some grains of brown hornblende.

Almandine occurs with hornblende and actinolite in a gneissose mafic body in Painted Canyon, at the contact between anorthosite and migmatite.

In some mafic bodies there are a few relict aggregates of oligoclase-andesine, partially replaced by fine-grained biotite, white mica, and hornblende.

The black oxides were evidently formed late in the emplacement history of all rocks. Aggregates of anhedral ilmenite or titaniferous magnetite envelop and fill fractures in apatite, amphiboles, and relict plagioclase. Kelyphitic rims of biotite, and to a lesser extent of sphene, surround many grains of black oxides. Some of the rocks contain ovoid aggregates of intergrown fine-grained magnetite, serpentine, talc and biotite, a secondary assemblage that suggests former olivine.

In places, the mafic bodies are cut by veinlets of carbonate, chalcedonic quartz, and fibrous bowlingite.

Basic Dikes

The basic dikes in the anorthosite group are fine-grained dark green to black rocks occurring as discontinuous dikes and lenticular bodies up to several feet in width. They clearly cross-cut rocks of the anorthosite group, but are most abundant in rock transitional between anorthosite and diorite, and are rare in gneiss at a distance from the complex. This close spatial relationship to the anorthosite group, as well as similarities in composition and texture, suggests a related origin.

Most dikes show a distinct layering and foliation, parallel to the walls, and nearly all are more or less sheared and fractured, although some are massive. Relict igneous textures, such as hypautomorphic and diabasic to lamprophyric, are at places discernible, although the textures are now largely recrystallized. Foliation, granoblastic textures, and mineral changes and alterations, described below, are interpreted as indicating metamorphism.

The rocks consist essentially of plagioclase and hornblende in roughly equal amounts, although generally hornblende exceeds plagioclase, by about 10 or 15 per cent. The assemblage hornblende–plagioclase, although also an igneous assemblage, is typical for a basic rock in the amphibolite facies of regional metamorphism.

The plagioclase is labradorite (An_{50}), occurring in some dikes as radiating bundles of laths up to 5 mm. long, and at places plagioclase laths penetrate hornblende. In the schistose dikes, plagioclase is largely altered to a mass of white mica and fine-grained epidote.

Hornblende with z = deep green or blue-green occurs as a closely knit aggregate of nearly euhedral prisms. In the schistose rocks hornblende prisms are subparallel, and they tend to be poikiloblastic.

Accessory minerals include ilmenite-magnetite (which forms up to 10 per cent of the rock), sphene, euhedral apatite, and scattered zircons. Epidote porphyroblasts occur in some sheared dikes.

Brown biotite is an alteration of hornblende; quartz, carbonate, and chlorite occur in veinlets.

ORIGIN AND HISTORY

The members of the anorthosite group are genetically related to one another, the main evidence for this being the close spatial relationships among the various rock types and the similarity in texture, composition, and mode of occurrence of the constituent minerals; this is shown especially in the transition from gabbro and diorite to anorthosite. The basic dikes, which transect the mafic bodies and other members of the group, appear to be the last intrusive event in the emplacement of the group.

The members of the anorthosite group were probably derived from a parent basic magma. Evidence of a magmatic origin is indicated by the following: (1) intrusive relations to gneiss; (2) rhythmic layering, probably due to crystal settling; (3) relict textures that are largely hypautomorphic granular; and (4) normal zoning in some of the plagioclase. The time sequence, begininng with the youngest, is: (1) basic dikes, (2) mafic segregations, (3) anorthosite, (4) transitional rock, and (5) gabbro and diorite. The relationships suggest that a gabbroic magma intruded gneissic country rock and differentiated in place, to yield diorite, transitional rock, and a later fraction of nearly pure plagioclase. Barely perceptible zoning, in the coarse-grained plagioclase, in part reflects relatively stable conditions of crystallization. Widespread fracturing and protoclasis took place late in the consolidation of the mass. This shattering, like that referred to by Higgs (1954), affected the nearly crystallized plagioclase without significantly displacing the crystals or milling them against each other. Later interstitial and fracture-filling plagioclase apparently crystallized from an intergranular liquid, following the shattering. The mafic bodies resulted from late enrichment in iron, titanium, phosphorous, and magnesium, and the basic dikes represent the latest intrusion of the gabbroic magma.

Metamorphism.—Rocks of the anorthosite group have been regionally metamorphosed, probably in connection with the intrusion of Mesozoic (?) granitic masses. This metamorphism is indicated by:

1. Basic dikes which cross-cut the group and are therefore younger display foliation with granoblastic textures.
2. Granoblastic and other typical metamorphic fabrics occur in the rocks of the group.
3. The group is widely and intimately transected by anastomosing dikes and bodies of alaskite (leucogranite), and locally broad zones of migmatite with deformed and gradational borders have formed. These field observations would seem to require metamorphism, even in those masses of the group most distant from alaskite and migmatite.
4. Many secondary mineral assemblages, although perhaps late magmatic in origin, are more likely metamorphic. The change from pyroxene to hornblende, and the destruction of olivine, are interpreted in this way. The mineral assemblages, including the hornblende-plagioclase assemblage of the basic dikes, implies an amphibolite facies for the group as a whole.
5. Widespread layering and foliation within rocks of the group are cut by

mylonitic and cataclastic zones in which the rocks have recrystallized. These zones are distinct from late shears, minor faults, and joints containing incoherent pulverized rock and gouge, which presumably formed during Cenozoic faulting.

Original pyrogenetic minerals such as olivine or pyroxene, if raised above a threshold of reaction during rising temperatures of regional metamorphism, could react to form hornblende or, with the addition of K_2O, biotite. The close association of gabbro, diorite, and anorthosite with syenite suggests that potash was present for the formation of biotite in the diorite and transitional rock during metamorphism. The coarse-grained hornblende in the massive diorite is probably original, and attainment of the amphibolite facies during regional metamorphism would probably result in no pronounced mineralogical change. Epidotization of the plagioclase is probably a late magmatic effect, although in part it could also be due to regional metamorphism, especially where the epidote is coarse grained and poikiloblasic.

Syenite and Related Quartz-Bearing Rocks

Syenite, as a general field term, includes a group of rocks characterized predominantly by potash feldspar and containing variable amounts of ferromagnesian minerals, plagioclase, and bluish-opalescent quartz. Included are blue-quartz granite and, where the quartz content exceeds 10 per cent and plagioclase is lacking, alkali granites. Granophyric and pegmatitic rocks, characterized also by blue quartz, are closley associated. Regional metamorphism has affected all of these rocks.

Syenite and associated rocks, here referred to as the syenite group, comprise, areally, about one-eighth of the exposed basement lying between the Orocopia Schist and the Clemens Well fault. The largest and most accessible mass lies at the northwestern end of the strip, between the two faults, and can be easily reached from Highway 195.

Both gradational and intrusive relations exist between syenite and gneiss. Quartz-bearing syenite grades into blue-quartz gneiss, with an increase in content of bluish quartz. At other places, sill-like bodies of syenite intrude gneiss. Migmatitic zones of leucosyenite intricately mixed with gneiss display deformed and gradational boundaries. Syenite close to the gneiss commonly has a well-defined foliation which results both from alignment of mafic clots and from concentration of blue quartz into layers. Alternating layers of blue-quartz rock and syenite produce a gneissic structure. In some places, lensoid masses of blue-quartz granophyre or pegmatite range up to several feet in width. These bodies tend to conform to foliation in the syenite, although in many places they occur as discordant and discontinuous flat lenses. Contacts are both sharp and gradational. Concentrations and layers of blue-quartz granophyre and pegmatite also occur well within gneiss. Some thin lenses of platy quartz, in gneissic quartz-bearing syenite, have resulted from partial mylonitization.

Farther removed from contacts with gneiss, the syenite is massive, and at places it is fractured and brecciated. Clasts in the breccia are both angular and rounded, and they range in size from very tiny to several feet across, fitting together tightly, without much interstitial material. They are composed of syenite cemented mainly by small amounts of brown carbonate. Fractures in the syenite form extremely irregular patterns and are healed either with brown carbonate or quartz. Throughout the syenite, shear zones and mylonitic streaks are common. Although brecciation, shearing, and cataclasis may be related to movements on nearby major faults, they seem to be too widespread for this origin. Perhaps they are the result of late magmatic shattering, after final emplacement, in a manner similar to that proposed by Higgs (1954, p. 203) for the San Gabriel anorthosite. It remains to be determined whether the carbonate within fractures was emplaced at this time or in connection with much later events, such as the intrusion of Mesozoic (?) rocks or Cenozoic faulting.

Rhythmic layering, possibly due to crystal settling, occurs locally. Layers are about 6 inches thick and at places extend laterally for 100 feet or so across the extent of an unfaulted outcrop. Each layer consists of a bottom portion of nearly pure ferromagnesian minerals, with black oxides grading upward into syenite or monzonite that is in sharp contact with the mafic bottom part of the overlying layer. Where observed, the attitudes of these layers conform closely to the foliation in nearby gneiss.

The syenite group and rocks of the anorthosite group are very closely associated spatially and are probably also closely associated in time. Gradational relationships between the two groups of rocks seem to be more common than intrusive relationships. Hornblende diorite, for example, with increasing quartz (usually bluish) and potash feldspar, grades imperceptibly into quartz-bearing syenite which, in turn, passes into mafic phases through monzonitic phases into syenite within about one hundred feet, and without definite contacts. Anorthositic bodies with gradational borders also occur within the syenite.

Several intrusive relationships are found which suggest that the syenite and related quartz-bearing phases might be somewhat younger than rocks of the anorthosite group: (1) inclusions of fine-grained diorite occur in dark syenite; (2) sharp contacts can be seen between fine-grained purplish syenite and epidotized coarse-grained diorite; (3) a dike of fine-grained syenitic rock, apparently stemming from a larger body of syenite, is present in coarse-grained gabbro; (4) discontinuous bodies of blue-quartz granophyre, like those associated with the syenite, intrude hornblende diorite.

PETROGRAPHY

Syenite, Quartz-Bearing Syenite, Blue-Quartz Granite, et cetera

The syenite, quartz-bearing syenite, blue-quartz granite, and alkali granite are dark brown to buff weathering, medium-grained rocks primarily with xenomorphic- or hypautomorphic-granular textures. In the strongly foliated syenite, there is granoblastic fabric and locally mylonitic structure. Fine- and coarse-grained phases are common. In some phases, the fresh surface is dark, due to a high content of ferromagnesian minerals. The potash feldspar is generally buff to brown or greenish, although in some of the mafic syenite it is purple or bluish. Quartz is blue-gray, blue, or violet.

The relative proportions of the constituent minerals are variable, although typically the rock consists of about 45 per cent microperthite, 20 per cent microcline or orthoclase, 10 per cent plagioclase, 15 per cent biotite, 5 per cent iron ore minerals, and the remainder quartz, apatite, hornblende, zircon, chlorite, fine-grained white mica, and carbonate. In the quartz-bearing syenite, blue-quartz granite, and alkali granite, the quantity of bluish quartz varies, with a relative decrease in feldspar or ferromagnesian content, from 5 to 30 per cent. The hornblende content increases with a corresponding increase in plagioclase.

Potash feldspar.—The microperthite grains are invariably xenomorphic and are of two distinct types. Of the two, the more common type shows very closely spaced, parallel, bladelike plates (less than 0.01 mm. thick) of oligoclase (An_{20}) in a host of microcline or orthoclase (pls. 4, *a*; 5, *b*). The proportion of plagioclase to potash feldspar is generally about half and half; with the regularity of intergrowth, this would seem to indicate an exsolution origin for this type of microperthite. It is similar to Eskola's "hair-perthite" in Scandinavian granulite (1952, p. 144) and it is also like the microperthite in syenite associated with the Adirondack anorthosite (Buddington, 1939, p. 282). In the second type, irregular patches and veins of potash feldspar replace twinned oligoclase (about An_{20}). Relicts of oligoclase with a common orientation occur within many large grains of microcline, and in some grains this results in a crude "chessboard" pattern. A distinctive feature in most of the syenite is a complete or partial rimming of the microperthite grains by clear quartz, or in some rocks by clear albite (pl. 6, *a*).

Of the nonperthitic potash feldspar, microcline with poorly developed grid twinning seems to be more common than orthoclase. Grains are xenomorphic in outline.

Potash feldspar is generally unaltered, but sericitization is common in shear zones. Many grains of microperthite, microcline, and orthoclase contain tiny needles of rutile oriented parallel to 001 or 010. The rutile probably gives the bluish tints to the feldspars as seen in hand specimen.

Plagioclase.—The plagioclase is oligoclase, An_{15-20}, found mostly as relicts within potash feldspar or as blebs in the exsolution microperthite. Unreplaced grains are subhedral to euhedral. Albite is found as rims around potash feldspar and as sodic borders of some oligoclase grains. In many specimens, the plagioclase is much more altered than the potash feldspar. Locally, plagioclase constitutes more than one-half of the total feldspar. Such rocks are monzonitic or dioritic.

Quartz.—Quartz with pronounced strain shadows occurs as mosaics of interlocking grains, either interstitial to or veining the feldspars. In the quartz-rich rocks, anhedral globules consisting of one or more quartz grains embay or produce an irregular sieve texture in the feldspars. Phacoidal aggregates of quartz have their long axes disposed parallel to foliation in the rocks.

Most of the quartz contains inclusions, many of which are tiny needles of rutile. Such inclusions probably account for the bluish or violet tints of the quartz as seen in hand specimen.

Mosaics of fine-grained quartz are commonly intergrown with biotite, black oxides, carbonate, and other fine-grained alteration materials, generally in the cores of mafic clots. Another common occurrence of quartz is in myrmekitic intergrowths, either with potash feldspar or plagioclase marginal to many large feldspar grains. The quartz which forms rims around feldspar grains has a mean refractive index very close to 1.54 and is probably a chalcedonic variety.

Ferromagnesian minerals.—No original pyrogenetic ferromagnesian minerals or any remnants of them were seen in any of the specimens of syenite. The original ferromagnesian mineral (or minerals) is now represented by clots of biotite, hornblende, black oxides, fine-grained white mica, or talc, sphene, leucoxene, epidote, chlorite, carbonate, and quartz. Any or all of these minerals occur together in an individual mafic clot, although biotite and black oxides predominate.

Many mafic clots are subrectangular in outline, and hornblende prisms or biotite flakes have a parallel arrangement. Fine-grained black oxides in the cores of some clots are disposed in a grid pattern, internally. Features such as these suggest that orientation of the secondary minerals was controlled by cleavages in an original pyroxene, either augite or hypersthene. Other mafic clots are ovoid in outline and consist of biotite, talc, and black oxides, an association which suggests original olivine.

Hornblende.—Hornblende rarely exceeds 10 per cent of the rock and is a green variety with $x =$ greenish yellow, $y =$ pale yellow, $z =$ deep green, and $z \wedge c = 14°$. In some thin sections there are a few needles of greenish-brown and pale yellow amphibole, with $z \wedge c$ about 5°. In the monzonitic rocks, aggregates of blotchy blue-green hornblende appear to have formed pseudomorphs after augite, to judge from the relict crystal form. Here the hornblende content exceeds that of biotite.

Hornblende commonly occurs in fringes of tiny parallel prisms around a core of fine-grained intergrown black oxides, leucoxene, quartz, and other secondary minerals. Such fringes of hornblende are partially mantled by fine-grained biotite flakes which grow parallel to the hornblende prisms.

Biotite.—Biotite composes most of the mafic clots and is generally fine-grained with $x =$ yellow or golden and $y + z =$ dark brown, greenish brown, green or reddish brown. A common occurrence of biotite is in aggregates of randomly oriented or radiating flakes either surrounding grains of black oxides or containing cores of fine-grained secondary minerals. Some mafic clots consist essentially of an intimate intergrowth of biotite flakes and fine-grained black oxides. In some thin sections, biotite clots poikilitically include parts of the feldspars, and trains of biotite flakes partially surround and vein the feldspars. Some grains of microperthite contain fine blades of biotite growing parallel to the exsolution blebs of plagioclase, evidently replacing the potash feldspar. This suggests a metamorphic reaction between an original ferromagnesian mineral and potash feldspar.

Textures exhibited by the mafic clots are metamorphic and can best be described by the terms (1) decussate, where the biotite occurs in aggregates of randomly oriented, tightly knit flakes, and (2) diablastic, where the biotite flakes are radiating and poikiloblastically include, or are intimately intergrown with, other secondary minerals.

Accessory minerals.—Most of the black oxides are late, as evidenced by their occurrence interstitial to and veining the feldspars. Fine-grained black oxides intergrown with other secondary minerals probably resulted from the breakdown of an original ferromagnesian mineral. It is possible, however, that some of the large anhedral black oxide grains surrounded by kelyphitic rims of biotite or sphene are early. The black oxide is titaniferous magnetite, commonly altered to leucoxene or hematite.

Abundant subhedral apatite is invariably included in the black oxides and mafic aggregates. Zircon is also abundant and occurs as scattered roundish grains throughout the rocks.

Alteration minerals.—Pale green chlorite is an alteration product of biotite. Fine-grained epidote and white mica occur in the cores of some mafic clots, or as cloudy alteration of plagioclase. Carbonate is widespread and occurs either as a fine-grained intergrowth with quartz in mafic clots, or in veinlets with quartz.

Blue-Quartz Granophyre and Pegmatite

Dikes and lenticular bodies of white-weathering granophyre and pegmatite, generally less than three feet wide, characterized by irregular intergrowth of alkali feldspar and blue quartz, occur within syenite, locally within diorite of the anorthosite group and as layers or irregular bodies in gneiss adjacent to syenite. Most of the bodies contain both pegmatite, in which the grain size is as much as four inches, and fine-grained granophyre. Both textural varieties intergrade within a single body. Some bodies contain a core of nearly pure blue quartz. Aligned mafic material and quartz-rich concentrations produce a foliation parallel to the walls of many bodies. In places, quartz lenses are streaked out into thin plates, apparently as the result of mylonitization.

These rocks are distinct from the alaskite (leucogranite) dikes which cross-cut them. Close spatial relationships and petrographic similarities suggest that the blue-quartz granophyre and pegmatite are genetically related to the syenite. Typically, the rocks contain about 50 per cent potash feldspar (mostly microperthitic), less than 5 per cent oligoclase, 30 per cent quartz, and negligible to 15 per cent biotite, plus black oxides. Apatite and zircon are common minor accessories.

Microperthite.—The microperthite is xenomorphic and very similar to that in the syenite, except that some grains are characterized by a rim of orthoclase with subparallel, flamelike interpositions of orthoclase crossing a plagioclase host. Replacement microperthite, in which potash feldspar replaces plagioclase in an irregular fashion, is more common than in the syenite. Some grains of potash feldspar contain rectangular relicts of plagioclase which form a "chessboard" pattern. Both microcline and orthoclase are found as the potash feldspar component in the microperthite. The plagioclase component is oligoclase (An_{20}) and is partially sericitized in the replacement type perthite. Many microperthite grains are partially rimmed by clear quartz and albite and are commonly microbrecciated (pl. 7, *a, b*).

Plagioclase.—Aside from the plagioclase in the microperthite, a few discrete, subidiomorphic grains of partially sericitized and epidotized oligoclase (An_{15-20}) occur throughout these rocks.

Quartz.—The blue-quartz grains are highly irregular in shape and show strong strain shadows. Quartz-feldspar intergrowths are irregular and complex. Quartz occurs as globular amoeboid grains and mosaic aggregates, which embay or form sieve textures with the feldspars. Myrmekitic quartz is common. Some of the quartz bodies enclosed in feldspar tend to have cuneiform, graphic outlines, and have the same optic orientation throughout the feldspar host.

The finer-grained rocks tend to be porphyritic, with larger grains of quartz or feldspar surrounded by finer-grained mosaics and granophyric intergrowths of quartz and feldspar.

Some of the rocks were brecciated, presumably at the same time as brecciation occurred in the enclosing syenite. The result is a microbreccia cemented by fine-grained quartz and fibrous chalcedony.

Biotite.—The ferromagnesian mineral, where present, is brown biotite occurring in streaky clots of randomly oriented flakes.

Alteration minerals.—Pale green chlorite is the principal alteration product of biotite. A few irregular flakes of white mica are also associated with the biotite. Sericite and fine-grained epidote minerals cloud much of the plagioclase. Carbonate and chalcedonic quartz occur in veinlets and brecciated zones.

ORIGIN AND HISTORY

A genetic relationship between the syenite group and the anorthosite group seems to be strongly indicated by (1) the very close spatial relationships, (2) the predominance of gradational features between the two groups of rocks, and (3) their position in the time sequence. Several intrusive relationships suggest that the syenite group is somewhat younger than the anorthosite group. Possibly these two groups constitute a comagmatic series of igneous rocks following a sequence: gabbro–diorite–anorthosite–monzonite–syenite–quartz-bearing syenite–potash granite–blue-quartz granophyre, and pegmatite. Mafic bodies appear to have formed in association with both anorthosite and syenite, but basic dikes were emplaced primarily in association with anorthosite. A late stage enrichment of an original gabbroic magma in K_2O, SiO_2, and FeO is accordingly implied. Such associations are common in anorthositic terrains throughout the world (Turner and Verhoogen, 1960, pp. 321–328).

Possibility of "ultrametamorphic" origin for syenite.—In many places, as was noted before, there are gradational relationships between syenite and gneiss. Both syenite and gneiss contain similar blue-quartz and replacement-type microperthite. Although the writers feel that the descriptions above support a magmatic origin for the syenite group, it is possible that the syenite is an ultrametamorphic rock derived in part by transformation of portions of the gneiss by hot intrusion of rocks of the anorthosite group, and to some extent by partial fusion of gneiss at great depths, to yield a magma of syenitic composition. The blue quartz might be fused and remobilized quartz of the gneiss. Such a palingenetic syenite magma could then reintrude gneiss and the anorthosite group, and itself differentiate to produce features like rhythmic layering and silica-rich end products of granophyre and pegmatite. Partial metasomatism of the gabbro or diorite by such a syenitic magma would explain gradational relationships between syenite and diorite.

If the original ferromagnesian mineral of the syenite and associated blue-quartz rocks were a pyroxene, the rocks would be texturally and mineralogically akin to charnockite (Turner and Verhoogen, 1960, pp. 324, 346). Especially from a structural viewpoint, they are similar to the charnockitic rocks described recently by Compton (1960), exposed in central California.

With the evidence to date, it can only be concluded that, whatever its ultimate origin, a large part of the syenite was emplaced as a magma, possibly as a sheetlike mass conforming to layering in the gneiss. Rhythmic layers, in places conforming to the attitude of layering in gneiss, seem to be the best indicators of this. It is possible that some of the gneissic quartz-bearing phases originated by metamorphic differentiation or resulted from assimilation of gneiss by syenite magma.

Origin of microperthites.—The two distinct forms of microperthite found in the syenite and related rocks seem to have different origins:

1. Exsolution-type microperthite is probably derived from a magmatic alkali feldspar which originally contained potash feldspar and plagioclase in solid solution. This is suggested by the uniformity in appearance and composition of that type of microperthite throughout the syenite. Uniformly spaced parallel blades of oligoclase, with constant width and having a nearly constant ratio of 50:50 per cent with respect to the potash feldspar in any grain, seem difficult to explain by metasomatic processes. Unmixing of oligoclase from an original magmatic alkali feldspar would probably require rather slow cooling conditions. It is possible also that unmixing took place during slowly falling temperatures, after regional metamorphism. In addition, shearing stresses related to metamorphism might have an activating effect on the unmixing processes. Similar perthites in granulites of Scandinavia are interpreted by Eskola as metamorphic (1952, p. 148).

2. Replacement-type microperthite results from partial replacement by potash feldspar of oligoclase formed earlier. Irregularity of the intergrowths and the general lack of a constant ratio between potash feldspar and oligoclase in any grain seem indicative of replacement processes.

It is likely that the replacement microperthite is the result of regional metamorphism and metasomatism, because similar microperthite occurs within the gneiss. A liquid enriched in SiO_2 and alkalies, mainly K_2O, has probably reacted with earlier formed minerals such as oligoclase. The quartz-albite rims around exsolution-type microperthite, as well as granophyric and other complex intergrowths of blue quartz and feldspar, were probably formed during this stage. Although many of these features could form as the result of late magmatic processes, the evidence for metamorphism of the anorthosite-syenite complex, discussed below, would seem to be incompatible with such an origin. Additional study of the replacement microperthite in order to determine its origin independently is highly desirable.

Metamorphism.—The rocks of the syenite group have also been regionally metamorphosed, apparently along with the anorthosite group. Although basic dikes are not as common in the syenite, some exhibit foliation and schistosity. Granoblastic and other metamorphic textures are common.

The syenite has probably attained at least the amphibolite facies of regional metamorphism, and possibly even the granulite facies, except for some retrogressive effects and later hydrothermal alteration. Although the mineral assemblage, biotite–hornblende–microperthite–oligoclase–quartz, is not necessarily proof of this, it would seem that such minerals as hornblende, microperthite and oligoclase would tend to be unstable in a grade of metamorphism lower than the amphibolite facies.

The mafic clots with subrectangular outlines in the syenite are probably derived from an original pyroxene. Pyroxene would go to biotite rather than to hornblende, in the presence of excess potash during regional metamorphism. Hypersthene, for example, could react with potash feldspar in the presence of water as follows:

$$\underset{\text{(Hypersthene)}}{6(\mathrm{Mg, Fe})\mathrm{SiO_3}} + \underset{\text{(Orthoclase)}}{2\mathrm{KAlSi_3O_8}} + \underset{\text{(Water)}}{2\mathrm{H_2O}} \rightarrow \underset{\text{(Biotite)}}{2\mathrm{K(Fe, Mg)_3AlSi_3O_{10}(OH)_2}} + \underset{\text{(Quartz)}}{6\mathrm{SiO_2}}$$

It was noted that many grains of black oxides are armored by biotite. During regional metamorphism, original magnetite could react with potash feldspar in the presence of water as follows:

$$\underset{\text{(Magnetite)}}{\mathrm{FeO \cdot Fe_2O_3}} + \underset{\text{(Orthoclase)}}{\mathrm{KAlSi_3O_8}} + \underset{\text{(Water)}}{\mathrm{H_2O}} \rightarrow \underset{\text{(Biotite)}}{\mathrm{KFe_3AlSi_3O_{10}(OH)_2}} + \underset{\substack{\text{(free oxygen, probably}\\ \text{recombines in other}\\ \text{secondary minerals)}}}{\tfrac{1}{2}\mathrm{O_2}}$$

Original oligoclase, microperthite, and quartz would probably remain relatively unchanged except for deformation, if raised to the amphibolite or granulite facies. It is possible that some of the sericitization of the feldspars is due to regional metamorphism, but this would be difficult to distinguish from earlier late magmatic effects, later retrogressive metamorphism, or very late hydrothermal action.

The presence of chlorite, sericite, and epidote is attributable, in all probability, to any or all of the late magmatic processes, retrogressive metamorphism, and late hydrothermal alteration. Carbonate and vein quartz are associated with later hydrothermal activity, shearing, and cataclasis.

Alaskite and Migmatite

Several large areas of alaskite (leucogranite) are exposed in the strip between the Orocopia thrust and the Clemens Well fault, but generally this unit consists of a maze of alaskite dikes that transect the gneiss and the anorthosite-syenite complex. These areas are mapped together as "alaskite and migmatite" (alm) and are the result of granitic intrusions of Mesozoic(?). The age is quite indefinite and is assigned to the Mesozoic only on the basis of analogy with other similar granites in southern California; the granitic rocks (alaskite) may be younger or older than Mesozoic, and until radiometric dates have been obtained the age is unknown.

Locally, these mixed rocks are very complicated. This is especially true where migmatitic rocks, which were formed at the borders of the anorthosite-syenite complex with gneiss, also correspond with the migmatitic borders of alaskite masses. Within such zones of "double migmatites" the original identity of many rocks is unrecognizable. In the area about a mile southwest of latitude 33° 35′ and longitude 115° 45′ (map 1), the border of the anorthosite-syenite complex with gneiss can be followed into a large mass of alaskite, and is a good place to observe this "double migmatite."

In some parts of the gneiss and anorthosite-syenite complex the alaskite dikes occur every few feet and form networks and branching systems. Where the proportion of mixed rocks is high, the terrane has been considered as migmatite. The larger dikes generally have sharp contacts and seem to be younger than the alaskitic material found in layers along the foliation of older rocks. At least two periods of alaskite emplacement are indicated: in some dikes a fine-grained phase can be seen cutting a medium-grained phase. The uniformity of mineralogy (30 per cent quartz, 65 per cent feldspar, and less than 5 per cent mafic material) of both rocks, and their close spatial relationships, suggest that both alaskites were emplaced at nearly the same time.

Boudinaging, and less commonly ptygmatic folding, of some alaskite bodies in the migmatites can be seen. Many dikes are weakly foliated parallel to the walls, and some are sheared and deformed.

PETROGRAPHY

The alaskite is pink to white weathering and typically medium-grained, although fine-grained and pegmatitic phases occur. The texture is typically hypautomorphic granular, but some of the finer-grained phases are xenomorphic granular or aplitic. Generally, the rocks are massive except for slight foliation in the thin injections and along some dike walls, where there is local late cataclasis as shown by granulation of quartz and feldspar.

The rocks range in composition from true granite, in the main dikes and pegmatites, where microcline forms more than two-thirds of the total feldspar, to quartz diorite in the narrow injections. Generally, the rock is quartz monzonite with about 30 per cent plagioclase (strongly zoned, subidiomorphic oligoclase-andesine, An_{5-45}), 35 per cent xenomorphic microcline, some microperthite, and 30 per cent xenomorphic, strained quartz showing sutured and interlocking boundaries with the feldspar, and some myrmekitic quartz intergrown with potash feldspar. Biotite ($x = \text{yellow}$, $y + z = \text{brown}$) is the only mafic mineral and forms less than 5 per cent of the rocks. Some of the granite has scattered poikilitic flakes of muscovite. Zircon is more abundant than apatite, and ilmenite is the opaque mineral.

The microcline is generally fresh, whereas the plagioclase is partially altered to sericite, epidote minerals, and albite. Microperthite, where present, is distinctly unlike that of the syenite, blue-quartz granophyre, and pegmatite.

Chlorite (penninite) is the common alteration of biotite. Carbonate occurs interstitial to feldspars and also in veinlets and intermixed with biotite. A few inclusions of epidote occur in the biotite.

ORIGIN AND HISTORY

The alaskite dike rocks and injections are probably related to nearby Mesozoic (?) plutons. Although the rocks were not all intruded simultaneously, their close spatial relationships suggest that they belong to one general period of intrusion much later than the blue-quartz granophyre and pegmatite. Some of the alaskite in the mixed rocks and migmatite may possibly be related to an earlier period of deep-seated partial fusion and remobilization of the gneiss.

In many places, the dikes and injections have been deformed and partially mylonitized. They have also undergone mild alteration, as shown by partial chloritization of biotite, and by epidotization and sericitization of plagioclase; but this may be a normal paulopost alteration, rather than alteration during the intrusion of Cenozoic volcanic rocks.

Southeast of Salton Creek Wash (near the corner of map 1), several other types of rocks are exposed. These include leucogneiss, gabbro or diorite, quartz diorite, medium-grained gray granite, and several types of volcanic rocks. Inasmuch as this area is within a U.S. Naval Bombing Range the rocks here have not as yet been mapped or studied.

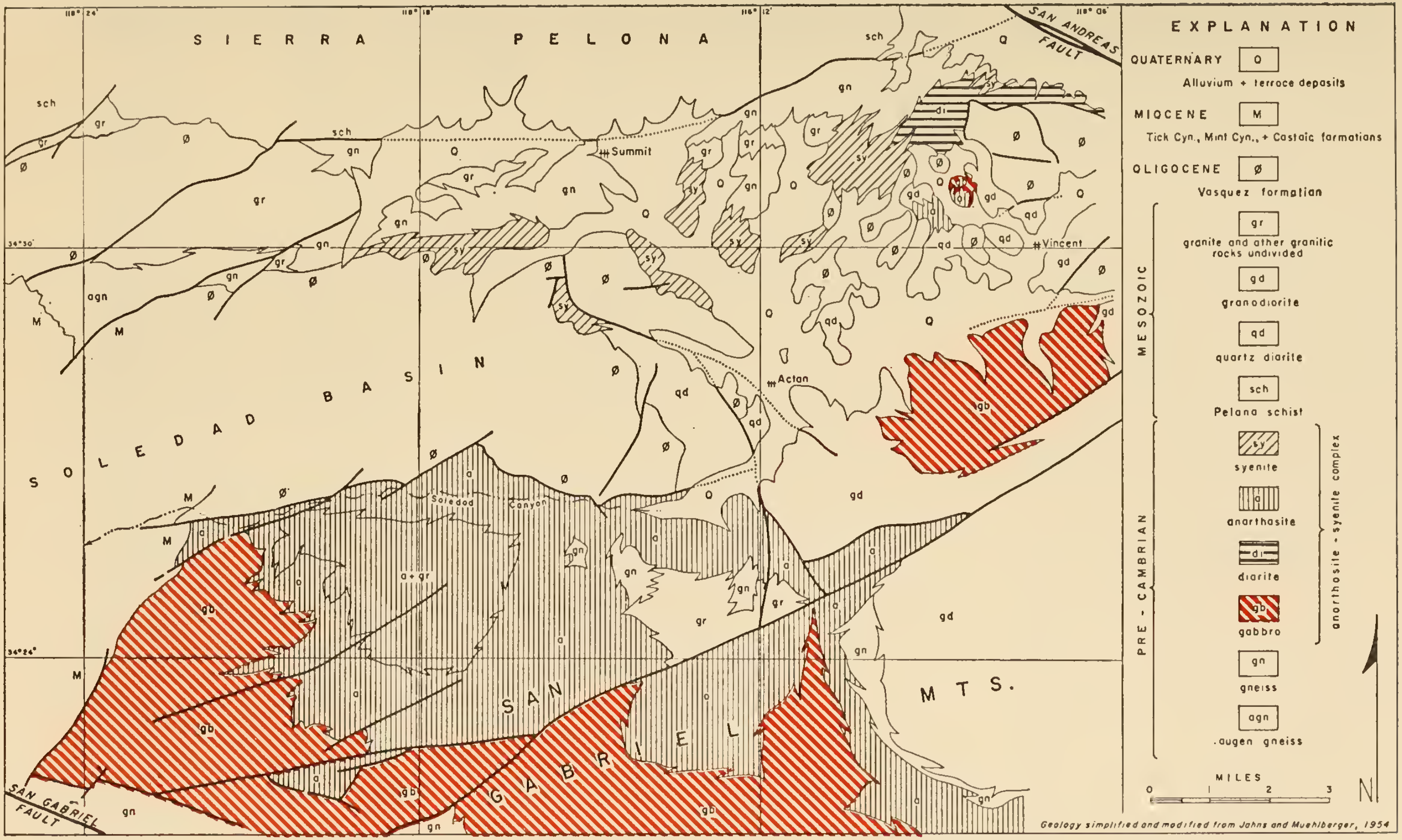
Other Rocks

The basement terrane of the Orocopia Mountains includes many types of hypabyssal and volcanic rocks in the form of dikes and irregular bodies. These include altered diabase, andesite, rhyolite, porphyry, and others. Some of the darker dike rocks have been altered and deformed, and these display schistosity parallel to the walls, although in most of them, a relict chilled margin is still preserved. A detailed study of these other rocks has not been undertaken. Some of the volcanic rocks are so young (probably late Cenozoic) that it seems likely they have been intruded after the principal displacement of the San Andreas.

SAN GABRIEL AREA

The San Gabriel Mountains and the adjoining Soledad Basin and Pass, in which anorthositic and syenitic rocks are also exposed, lie north of Los Angeles, in the central part of the Transverse Ranges (fig. 1, and map 2). The region of interest is easily reached by U.S. Highway 6, Angeles Crest Highway, or Soledad Canyon Road. The more humid climate of this region is largely responsible for deeper weathering and brush, so that exposures are not as fresh or as complete as in the Orocopia Mountains. Several workers have described the geology and have dealt with the petrology of the rocks (Miller, W. J., 1934; Higgs, 1954; Jahns and Muehlberger, 1954; Muehlberger, 1958; and Oakeshott, 1937, 1948, 1958). The contributions of these previous workers have been most helpful as foundation for the present work. Inasmuch as these papers contain many field photographs, none is included here.

In general, the geology of the western San Gabriel Mountains–Soledad region consists of a basement complex overlain by folded and faulted Tertiary sedimentary units that are assigned to several formations (Jahns and Muehlberger, 1954).



Map. 2. Geologic map of eastern Soledad basin and northwestern San Gabriel Mountains, southern California. Geology simplified and modified from Jahns and Muehlberger, 1954.

The basement is comprised of gneiss, invaded by gabbro, diorite, and anorthosite, which are Precambrian in age (Neuerburg and Gottfried, 1954; Silver *et al.*, 1960), and rocks of the closely associated syenite group. These, in turn, have been intruded, probably in the Mesozoic, by several later granitic bodies. On the west are large sectors of gneiss, augen gneiss, and associated migmatite. On the north lies Sierra Pelona, composed of greenschist—the Pelona Schist. With the exception of the gneiss and the greenschist, rocks similar to those of the San Gabriel–Soledad area are not yet known from other areas in the Transverse Ranges. A few fault slivers of anorthositic rocks occur along the northwestern course of the San Gabriel fault (fig. 1). Exposures of diorite and gabbro are found north of the principal part of the San Andreas zone, in the Valyermo quadrangle (Noble, 1954).

As in the previous part of this report, each of the basement rocks is described below in turn, beginning with the oldest.

GNEISS

The gneiss with which we are concerned borders the anorthosite group on the south and east, and borders the syenite on the north. The belt of gneiss on the south, named the Mendenhall gneiss by Oakeshott (1958, p. 21), is about 8 miles long and averages a mile in width. It trends S. 80° E., bounded on the south by the San Gabriel fault. Dips of foliation within this belt are generally steep to the southwest. Belts on the east are narrow and discontinuous, and they seem to wrap around the eastern nose of the anorthosite. The belt north of the syenite follows the southern edge of the Sierra Pelona to the San Andreas fault zone; it is about 12 miles long and averages a mile in width. It trends about N. 80° E. and dips vertically or steeply to the north. The gneiss is thrust onto Pelona schist to the north, and grades into syenite to the south, and into augen gneiss on the west.

The southern belt of gneiss contains "lit-par-lit" injections of granitic material, as well as discontinuous bodies of rock which in hand specimen are similar to the syenite occurring north of the anorthosite group.

The gneiss ranges from black amphibolite to blue quartz-bearing leucogneiss with variable amounts of hornblende and biotite. Some of the gneiss has distinct layers of blue quartz and varying amounts of white feldspar, and is locally mylonitic.

The gneiss is cut by dikes of both anorthosite and gabbro, also by later granitic dikes, and it has undergone at least two periods of metamorphism, one before the intrusion of the anorthosite group in the Precambrian, and the other related to the intrusion of granitic rocks in the Mesozoic (?). Widespread regressive metamorphism is also evident.

PETROGRAPHY

The gneiss consists of distinct layers rich in hornblende or biotite, alternating with those rich in blue quartz and feldspar. Layers vary in width from a few millimeters to several feet. Some of the rocks show igneous-looking textures. Black amphibolite, for example, exhibits blastodioritic or blastophitic textures, either resulting from penetration by basic magma bordering diorite and gabbro, or possibly inherited from an older diorite or diabase.

Amphibolite.—Amphibolite comprises about one-tenth of the mass and is intercalated with lighter-colored gneiss. The rock is medium-grained granoblastic and dark greenish-gray to black. A typical composition is about 45 per cent xenoblastic to poikiloblastic plagioclase (An_{30-50}), 25 per cent blue-green or brown hornblende, which is found as nematoblastic prisms or poikiloblastic plates, and occasional pyroxene (diopside). Some specimens contain minor xenoblastic quartz. Scattered zircon and apatite are common. Other constituents include biotite (which takes the place of as much as half the hornblende, in some specimens), chlorite, calcite, muscovite, epidote, sieve plates of sphene, and some black oxides.

Quartzo-feldspathic gneiss.—This rock is medium grained, and white to blue-gray in color. It contains varying amounts of xenoblastic plagioclase (An_{25}) and some albite, probably derived from regressive metamorphism. Twin lamellae of the plagioclase are generally deformed. Xenoblastic microcline and microperthite with fine, closely spaced blebs are common. Grid twinning in the microcline tends to be indistinct. Patch-type perthite is formed where irregular bodies of potash feldspar have replaced part of the plagioclase.

Bluish quartz forms up to 40 per cent of some specimens and occurs mainly as irregular masses embaying the feldspar. Quartz also occurs as myrmekite intergrown with microcline, as a granoblastic mosaic with feldspar, and as a fine-grained mosaic intergrown with hornblende and biotite. In the mylonitic phases of the northern belt of gneiss, ragged grains of blue quartz occur within lenticular ribbons alternating with layers of waxy-looking sericitized feldspar.

Hornblende is subidioblastic with x = light yellow-green, y = dark green, z = blue green. The biotite commonly has x = yellow, y + z = brown and is poikiloblastic or occurs in clots largely altered to chlorite, leucoxene, and magnetite.

Pink garnet occurs in some specimens and is armored by pale yellowish-green chlorite. In the same rocks, the plagioclase is almost entirely replaced by fine- to medium-grained white mica. Other secondary minerals include epidote, both as fine-grained aggregates and as medium-grained porphyroblasts, and calcite as irregular masses and veins.

Euhedral zircons are common. The black opaque mineral is magnetite occurring as subhedral grains, irregular masses, or as a fine-grained alteration product.

ORIGIN AND HISTORY

The dark amphibolite, especially that showing igneous-looking textures, and distant from bodies of gabbro and diorite, is possibly derived from basic volcanics or older basic intrusives. The assemblage hornblende–biotite–oligoclase–quartz–sphene is typical of the amphibolite facies of regional metamorphism, and the other gneisses interlayered with the dark amphibolite can thus be referred to the same facies. The presence of minor pyroxene in the amphibolite suggests the possibility that the gneiss in part borders on the granulite facies.

Some of the quartzo-feldspathic gneiss could have been either sandstone or acidic igneous rock, and the finer-grained gneiss of intermediate composition could have been derived from tuff or shale. Such an assemblage as quartz–microcline–oligoclase–biotite–white mica belongs high in the amphibolite facies.

In the mylonitic blue-quartz gneiss the metamorphic assemblage before regression was apparently quartz–plagioclase–biotite–garnet. Regression has resulted in the following changes:

garnet → chlorite
biotite → magnetite, leucoxene, chlorite
feldspars → white mica

Some of these effects may be due to late hydrothermal alteration instead of retrograde metamorphism.

ANORTHOSITE GROUP

The anorthosite group in the western San Gabriel Mountains crops out as an elliptically shaped mass extending 20 miles from east to west and 10 miles from north to south. Several isolated exposures extend to the northeast, including one two miles northwest of Vincent and about three miles from the San Andreas fault; and some, discussed below, occur in the Valyermo Quadrangle (Noble, 1954) north of the fault, in an anomalous position.

The anorthosite group includes the following rock types, all of which have undergone regional metamorphism:

1. Basic dikes.
2. Mafic bodies.
3. Anorthosite, which comprises about 50 per cent of the complex.
4. Gabbro and diorite; spotted rocks transitional to anorthosite, minor quartz-diorite and monzonitic phases.

On the south and east, the anorthosite group is partly mantled by gneiss and is partly in contact with later granitic rocks. On the north and west, most of the group is in fault contact with Tertiary rocks of Soledad Basin. In the west, the anorthosite has been extensively invaded by granite and pegmatite (map 2, *a* and *gr*).

The relations of the group to older rocks is shown by dikes of anorthosite, gabbro, and basic dikes, which cut the gneiss, and by isolated roof pendants and inclusions of gneiss within the anorthosite complex. Portions of the gneiss appear to grade into gabbro or anorthosite, and were probably reconstituted by the basic magma along some contacts.

No contacts between the anorthosite group and syenite were observed. Gneiss bordering the group on the south contains local syenitic variations, and the anorthosite group is reported by Oakeshott to contain local monzonitic variations rich in microperthite (1937, p. 227). Though probably closely related to the anorthosite group in origin, the syenite group, which is exposed mostly two to three miles to the north, is a distinctive group of rocks and is described separately.

The anorthosite group consists essentially of three major phases: (1) norite,[1] gabbro, and diorite; (2) anorthosite; and (3) transitional rock between gabbro and anorthosite. Additional minor phases are mafic bodies and basic dikes. The over-all distribution of these rocks shows no well-defined structure for the mass. Throughout most of the mass, strikes of primary layering and foliation are variable, and dips are relatively steep. In the western part, however, there is an apparent systematic distribution of rock types and attitudes. Here the gabbro (Higgs, 1954) occurs along the border and extends inward, toward the central part of the mass. It is succeeded in turn by transitional rock and then by anorthosite, which constitutes the core. The primary layering and foliation in most places dip steeply toward the border.

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[1] Norite, or hypersthene gabbro (Higgs, 1954), is a field term referring in general to the predominantly medium-grained basic phase of the complex. Actually, much of this rock is not true norite, and it grades into gabbro and diorite. In order to simplify our terminology, we have not used the term.

Gabbro and diorite show an increase in grain size toward the transitional rock. Layering, which is poorly developed, ranges in thickness from a fraction of an inch to several feet. Crystal settling may have been operative in producing much of the layering, especially in layers which show a gradation from pure plagioclase to pure aggregates of mafic minerals. Discontinuous alignment of mafic constituents is common and has probably resulted in part from primary magmatic flow, in part also from deformation and metamorphism. Fine-grained dioritic and gabbroic layers in the anorthositic rocks three miles northwest of Vincent probably represent more quickly cooled portions of parent magma injected into older, already crystallized layers.

Gabbro and diorite grade into the transitional rock, which is characterized by a steady increase in plagioclase content and grain size toward the anorthosite. Discontinuous layers defined by variable proportions of plagioclase and ferromagnesian minerals occur on a much grosser scale than in the gabbro and diorite. Individual layers up to 60 feet thick have been observed. Where the ferromagnesian minerals are aligned or concentrated in layers, the rocks are gneissic. Scattered grains of altered hypersthene impart a spotted appearance to much of the transitional rock.

Most of the anorthosite in the core of the mass is coarse grained, and it intergrades with transitional rock. Medium-grained gabbro or diorite, however, is found locally in sharp contact with coarse-grained anorthosite. On the other hand, medium-grained anorthosite cuts sharply across foliation in gabbro and transitional rock, as can be seen, for example, along the south side of Soledad Canyon. Anorthosite also occurs as lenticular concentrations up to 50 feet wide and several hundred feet long. Contacts of these bodies are generally sharp, and shears are present in wall rocks.

Numerous lenticular and dikelike mafic bodies, composed predominantly of ilmenite, apatite, and ferromagnesian minerals, occur throughout the anorthosite group, but most of them are in the transitional rock. These bodies range in size from only a few inches wide to large lenses several tens of feet thick and hundreds of feet long. They are mostly massive, although some bodies show layering of the constituent minerals, and many are schistose, adjacent to wall rocks. The mafic rocks appear to represent late concentrations that filled fractures in the anorthosite group. Some have been mined for titanium.

Basic dikes ranging in width from a few inches up to several feet cut the anorthosite group and surrounding gneiss, as well as the mafic bodies. The dikes display relict diabasic or lamprophyric textures, although in the main they are granoblastic. These relict textures, along with foliation, shears, alteration, and deformation, indicate that they are metamorphosed and are distinctly older than similar dikes of Mesozoic (?) and Tertiary age. The occurrence of sets of discontinuous dikes well within the anorthosite mass suggests a genetic relationship between the dikes and the anorthosite.

Fault, shear, and fracture zones transect all rocks of the anorthosite group. The relatively steep dip of what is assumed to be primary layering and foliation may be the result of deformation and tilting of the mass. Some of the gneissic foliation is possibly also a result of early deformation and metamorphism, especially where there is accompanying alteration of primary minerals.

PETROGRAPHY

Gabbro, Diorite, and Transitional Rock

The gabbro and diorite are typically medium grained, with local coarse- or fine-grained variations, and are xenomorphic- to hypautomorphic-granular in texture. Metamorphism has apparently left much of the igneous texture intact. Depending on the mafic content, the rocks are mottled dark bluish-gray, green, or greenish-black, on fresh surfaces, and they weather brown or black. Mottling is due to light blue-gray plagioclase set in a dark ferromagnesian matrix.

Textures in the transitional rocks are variable, and the grain size tends to be exceedingly coarse. Hypautomorphic textures are common, but large-scale poikilitic and subophitic textures, in which grains of altered hypersthene contain subhedral to euhedral plagioclase crystals, are present. The plagioclase crystals, which attain lengths of one to five feet, but are more commonly two to six inches in size, are elongate parallel to the "a" crystallographic axis and are more or less aligned parallel to megascopic layering in the transitional rocks. The hypersthene crystals, which are also generally aligned parallel to layering, range up to 10 feet in their greatest diameter (Higgs, 1954, p. 186).

The medium-grained gabbro and diorite have a higher ferromagnesian content than the coarse-grained transitional rocks. They contain about 50 per cent plagioclase, 40 per cent pyroxene, occasional olivine in mafic parts, 10 per cent black oxides, and minor apatite and sphene. The pyroxenes include both hypersthene and augite, which are mostly replaced by hornblende or, in some specimens, by biotite. In some dioritic phases, northwest of Vincent and in those northwest of Valyermo, coarse hornblende seems to be a primary constituent.

Locally, the gabbro and diorite contain abundant epidote which entirely replaces plagioclase, in some specimens. Some of the less mafic diorite contains appreciable quartz, and at places is a quartz diorite.

In the transitional rocks, the mineral composition is extremely variable. Essentially, the rocks contain up to 90 per cent plagioclase, with variable amounts of altered hypersthene and black oxides.

Anorthosite

The anorthosite, whether medium-grained as in lenticular concentrations, or coarse-grained as in the main body of the mass, was originally hypautomorphic in texture. Some of the medium-grained anorthosite contains interstitial fine-grained plagioclase which may have been derived from protoclastic brecciation of larger plagioclase grains, or possibly from recrystallization during metamorphism. This is a common feature in the exposures northwest of Vincent and in those northwest of Valyermo. Relict xenomorphic-granular textures, although the rocks are now large granoblastic, are recognizable in some of the medium-grained rocks. The anorthosite is massive, but there is some alignment of plagioclase crystals parallel to layering, in nearby transitional rocks. In the lenticular anorthositic bodies, occasional mafic constituents are elongated parallel to walls. The anorthosite is white-weathering and bluish-white on fresh surfaces, and most of it is fractured in an irregular fashion, many of the fractures having been healed with finer-grained plagioclase.

Mineralogically, the anorthosite consists of 95 to 99 per cent plagioclase. Occasional grains of hypersthene and black oxides, and a little interstitial quartz and albite, occur in some specimens. In some parts of the anorthosite, particularly near the northern margin of the mass, epidote replaces nearly all of the plagioclase.

Mineralogy of the Anorthosite Group

Plagioclase.—Andesine[2] (An_{25-45}) is the typical plagioclase throughout most of the group. On this basis, much of the gabbro and transitional rock is hypersthene diorite and hornblende metadiorite. Some of the medium-grained xenomorphic rock near the margin of the mass contains labradorite (An_{50-60}), as well as more augite than hypersthene, and it should therefore be classified as gabbro. The labradorite is anhedral, clear, and characterized by complex twins with relatively wide lamellae.

There are two types of andesine, particularly in the anorthosite and transitional rock (pl. 2, *b*): (1) medium- to coarse-grained, relatively uniform in composition, and charged with tiny inclusions of epidote minerals; and (2) fine- to medium-grained, strongly zoned, and generally free of inclusions. Zoning in the second type is normal, with cores as calcic as An_{45}. The average anorthite content of the finer-grained plagioclase seems to be at least five per cent higher than in the coarser-grained type. This is probably because most of the volume of the smaller grains is contained in the calcic cores, and in the coarser grains part of the calcium has entered the epidote inclusions. Zoning in the medium- to coarse-grained plagioclase is commonly imperceptible, especially in the extremely coarse-grained anorthosite. Exceptions to this are the zoned subhedral to euhedral andesine crystals that are mantled by thin shells of sodic oligoclase or albite. In hand specimens, these sodic borders are white, contrasting with the bluish color of the enclosed andesine. In specimens of anorthosite where plagioclase is medium- to fine-grained, the zoning tends to conform to the outlines of grains in the medium-grained plagioclase. In the epidotized rocks, zoning in the plagioclase is irregular and the andesine is embayed by irregular areas of more sodic plagioclase.

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[2] Higgs' (1954) plagioclase determinations for the whole complex showed a range An_{38-46}, averaging An_{43}. This is a reasonable average for plagioclase in the anorthosite and transitional rocks. Oakeshott (1958, p. 33) also obtained an average of An_{43}.

The finer-grained andesine occurs as a granular mosaic, interstitial to and filling fractures in the coarser-grained cloudy andesine. This occurrence seems general throughout the anorthosite and transitional rocks. Many large anhedral plagioclase grains have granulated borders and bent or offset twin lamellae. Irregular fractures transect most of the plagioclase without regard to cleavage or grain boundaries, and rarely do the fractures occur in sets. Larger fractures are healed with a mosaic of fine-grained clear andesine, and smaller ones with carbonate, quartz, albite, and chlorite. All these features are probably protoclastic, because in general they do not seem to be related to later Cenozoic cataclastic zones. It is possible that some of the finer-grained plagioclase owes its origin to the partial reduction in grain size of the coarser-grained plagioclase during metamorphism. This possibility, however, has not been thoroughly explored.

In the hornblende diorite and gabbro near the margin of the mass, much of the plagioclase is altered to a dense mass of fine-grained epidote, sericite, and kaolinitic material. Sericitization of the plagioclase is common in the sheared portions of the complex.

Quartz.—Very small amounts of quartz, at places bluish but usually gray in color, are distributed throughout rocks of the group. In places it is of sufficient abundance, in dioritic phases, to warrant the term quartz diorite. Small amounts of quartz also occur as fracture fillings.

Hypersthene.—The primary hypersthene in the anorthosite group occurs as relicts within secondary minerals, although a few fresh subhedral prisms are seen in some thin sections of medium-grained gabbro. The hypersthene has altered to hornblende, biotite, chlorite, and black oxides. The primary hypersthene crystals seem to have been subhedral to euhedral in outline, and poikilitically include euhedral plagioclase, in some parts of the transitional rocks.

Olivine.—Most of the primary olivine has altered to aggregates of serpentine, talc, and black oxides. A few fresh relicts occur in mafic gabbro and the mafic bodies.

Augite.—The clinopyroxene in the medium-grained phases of the complex is augite with $z \wedge c = 40°$, 2V about 60° and reddish-brown to colorless pleochroism. Unaltered augite occurs as anhedral to subhedral crystals, but rarely as clear relicts within hornblende crystals. Augite relicts within any one hornblende crystal have the same optic orientation.

Hornblende.—The hornblende is a blue-green variety with $x =$ yellow, $y =$ dark green, $z =$ blue-green and $z \wedge c = 18°$. Much is blotchy and sieve-textured, due to numerous inclusions of plagioclase, sphene, apatite, and black oxides. Some grains are ragged in outline, although relatively well-formed hornblende prisms occur in the dioritic phases of the group. Blue-green hornblende also occurs in irregular poikiloblastic aggregates composed of small subhedral prisms intermixed with biotite flakes and black oxides.

Another amphibole (probably cummingtonite), fine-grained, acicular and pale olive drab to brownish with $z \wedge c = 10°$, occurs with the blue-green hornblende where amphiboles form pseudomorphs after augite or hypersthene. Both amphiboles form uralitic aggregates with pyroxene outlines. The blue-green hornblende occurs chiefly around the rim, and the brownish amphibole grows generally parallel to pyroxene cleavage, within the aggregate.

In one specimen of mafic gabbro, subidiomorphic stubby prisms of brown hornblende occur with pyroxene and labradorite.

Biotite.—Biotite with $x =$ pale yellow, $y + z =$ golden brown occurs as mantles around grains of black oxides, and in some of the dioritic rocks is intergrown with hornblende. Some parts of the diorite, in the northeastern part of the mass, contain biotite as the principal ferromagnesian mineral, and where the rocks are sheared or gneissic, the biotite flakes wrap around grains of plagioclase or black oxides.

Accessory minerals.—The black oxides include ilmenite and titaniferous magnetite, occurring in anhedral grains or veinlike masses. A few isolated grains are euhedral. Generally, the black oxides seem to be later than the feldspar and the primary ferromagnesian minerals. Irregular masses of black oxides occurring within hornblende aggregates are commonly mantled by sphene, and where they are in contact with plagioclase are mantled by epidote. Fine-grained black oxides occur within much of the hornblende and grow along the amphibole cleavage.

Apatite forms up to 15 per cent of some medium-grained gabbro. Crystals are subhedral, and they commonly occur with black oxides. Tiny crystals of apatite also occur as inclusions in the plagioclase of the anorthosites.

Sphene is common in the medium-grained gabbro and diorite. It occurs both as subhedral to irregular granules and as rims around black oxides.

Occasional tiny rounded grains of zircon are found in most specimens, especially in the plagioclase of the anorthosite.

Alteration minerals.—Epidote minerals are the common alteration products of plagioclase: (1) fine-grained saussuritic aggregates, possibly resulting from late magmatic processes, metamorphism, or later hydrothermal action; and (2) coarser-grained poikiloblastic epidote, probably resulting from metamorphism and possibly from late magmatic processes.

Chlorite is the main alteration product of biotite and hornblende. Serpentine and talc replace most of the olivine. Sericite is another alteration product of plagioclase. Leucoxene and hematite are the principal alteration products of black oxides. Carbonate and quartz are found mainly in veinlets.

Mafic Bodies

Rocks of the mafic bodies, which occur as lenses or dikelike masses, are medium-grained, dark green to black, and they weather brown. Although they are mostly massive, many show segregation layering of constituent minerals. Textures are complex and include both relict igneous hypautomorphic textures and metamorphic fabrics, such as granoblastic textures and schistosity.

Mineral assemblages are variable. Primary, metamorphic, and late alteration minerals are all present in most specimens of the rocks. Some of the small bodies, and individual layers within larger bodies, are essentially massive aggregates of ilmenite and titaniferous magnetite. Many of the rocks contain as much as 25 per cent of euhedral apatite, which occurs mostly as poikilitic inclusions within grains of black oxides and relict ferromagnesian minerals. Variable amounts of olivine, hypersthene, and augite occur as sieve-textured relicts. Olivine is mostly altered to fine-grained aggregates of black oxides, talc, and serpentine. Hypersthene and augite are replaced by blue-green hornblende and fibrous pale-brown amphibole. Some specimens consist essentially of a felted aggregate of amphibole and interstitial chlorite; subidioblastic prisms of blue-green hornblende, brown hornblende, and fine-grained, pale-brown to colorless amphibole are present. The hornblende has fibrous terminations, and most of the brown hornblende shows rims of pale-brown to colorless amphibole. Some specimens contain a few relicts of andesine which are embayed and veined by black oxides, and in places they are surrounded by kelyphitic rims of serpentine. Biotite and sphene occur as rims around the black oxides. The biotite is dark brown or reddish-brown and is partially pseudomorphed by chlorite.

Basic Dikes

Basic dikes associated with the anorthosite group are dark green to black, and are generally fine-grained rocks, medium-grained in the center and schistose at the margins. They range from less than a foot to 20 feet in thickness. Mostly, the rocks are massive, although some show layering of dark and light minerals, parallel to dike walls. Schistosity is common, and is generally parallel to walls.

Regional metamorphism, as shown by schistosity and granoblastic textures, has resulted in recrystallization of the dikes, but original igneous textures are readily apparent. Relict textures, especially toward the centers, are xenomorphic to hypautomorphic, and locally lamprophyric.

Hornblende and plagioclase, present in the proportions 60:40 per cent, are the essential constituents. The assemblage is characteristic of the amphibolite facies of regional metamorphism.

The plagioclase is anhedral to subhedral labradorite (about An_{50}). In some rocks it is lath-shaped, and a few grains are strongly zoned. In the sheared and foliated rocks, most of the plagioclase is clouded with sericite and epidote.

Hornblende with z = deep green or blue-green occurs as long, subidioblastic prisms interlaced throughout the rocks. Many grains are poikiloblastic, with inclusions of plagioclase, sphene, and black oxides.

Common accessory minerals are scattered subhedral grains of black oxides, apatite, and anhedral granules of sphene. Poikiloblastic epidote aggregates are common in the schistose dikes.

ORIGIN AND HISTORY

A genetic relationship among the members of the anorthosite group is evident from the following observations:

1. All the constituent rock types occur within, or very close to, one large mass.

2. Gradational features are evident, in particular the similarities and transitional features in mineralogy and textures, from gabbro or diorite, through transitional rock, to anorthosite.

Evidence of a magmatic origin for the complex includes:

1. Intrusive relations to older gneiss.
2. Auto-intrusion, such as anorthosite dikes cross-cutting older basic members of the group.
3. Segregation layering in places, apparently due to crystal settling.
4. Textures (for example, hypautomorphic-granular) are igneous, except for superimposed metamorphic effects.
5. Presence of plagioclase with relict normal zoning.

The major rock types of the group can be arranged in relative age, from youngest to oldest, as follows:

Basic dikes.
Mafic bodies.
Anorthosite.
Transitional rock.
Gabbro and diorite.

Little new evidence has been discovered to elucidate the structure and mode of emplacement of the anorthosite group. The domal shape of the gabbro, transitional rock, and anorthosite in the western sector of the complex (Higgs, 1954) suggests a possible floored intrusion, now tilted westward and deformed. Under this hypothesis, the gneissic belt on the east might be the laccolithic floor. If much or part of the segregation layering is due to crystal settling, an original horizontal or subhorizontal attitude for the layers would be assumed, although strong evidence in favor of this interpretation is lacking. The present steep dips of layering in the mass would then be due, quite possibly, to laccolithic doming as later anorthositic magma was emplaced, to deformation of the complex during emplacement of nearby Mesozoic (?) batholiths, and to tilting during the Cenozoic.

The bordering gneiss represents the country rock into which the original gabbroic magma was intruded. Probably much of the magma differentiated in place under relatively stable conditions, as suggested by segregation layering, gradational relationships, and lack of zoning in most of the older plagioclase. The anorthositic fraction underwent some preconsolidation movement and shattering. This is suggested by protoclastic textures and the presence of a later finer-grained interstitial and fracture-filling plagioclase, and is most easily explained by deuteric explosion (Higgs, 1954, pp. 202–206).

The mafic bodies in the mass indicate late enrichment of the magma with iron, titanium, magnesium, and phosphorous. The latest intrusions of gabbroic magma are represented by the basic dikes.

Metamorphism.—Rocks in the anorthosite group have been regionally metamorphosed, probably in association with the emplacement of the surrounding Mesozoic (?) granitic masses. The late basic dikes, which are commonly schistose, are in the amphibolite facies, as indicated by their mineral assemblage: hornblende-plagioclase. The earlier rocks in the group have thus attained at least the same grade of metamorphism. Granoblastic texture, gneissic layering in transitional rocks, and local schistosity are other features interpreted as due to metamorphism. The association of later granite and anorthosite, which are intimately mixed in several large areas (map 2, *a* and *gr*), might be expected to accompany metamorphism.

Original andesine and hornblende could be expected to remain relatively unchanged in the amphibolite facies. Probable changes induced by regional metamorphism in these minerals, aside from deformation effects, appear to be: development of blotchy blue-green hornblende with decreased cloudiness, and possible reduction in grain size, of some of the andesine. The breakdown of the pyroxenes to amphiboles, sphene, and black oxides, and of olivine to talc, was probably initiated by a sufficient rise in temperature in the presence of water, during regional metamorphism, although conceivably the same changes could be paulopost (Higgs, 1954, fig. 17). Biotite resulting from the alteration of pyroxene or hornblende implies the presence of potash, especially near the margins of the complex. Here the syenite and later Mesozoic (?) intrusives are likely sources of potash. Epidote, where it is medium- or coarse-grained and poikiloblastic, may also be a product of regional metamorphism.

Although the rocks show distinct changes in mineralogy, the study has not been penetrative enough to distinguish between those which are paulopost, those which resulted from regional metamorphism, and those which formed during regression. In some specimens, shreds of biotite, for example, replace feldspar in the exsolution-type microperthite. Chlorite, sericite, and epidote are in the same group. Carbonate and quartz veins are conspicuous in shear and cataclastic zones that are considered somewhat older than those credited to Cenozoic faulting; these veins may therefore be associated with hydrothermal activity, perhaps in the Mesozoic.

Syenite and Related Quartz-Bearing Rocks

Most of the syenite crops out along the southern edge of the Sierra Pelona, in a belt averaging 1½ miles in width (map 2). It extends northeasterly for about 14 miles, almost to the San Andreas fault zone. Small syenite bodies also occur with the gneiss which bounds the anorthosite on the south, in the western San Gabriel Mountains.

The syenite is characterized by potash feldspar and varying amounts of ferromagnesian minerals, plagioclase, and bluish-opalescent quartz. Included with it are monzonite and blue-quartz granite. Rocks that contain more than 10 per cent quartz, and in which plagioclase is inappreciable, are called alkali granite. Granophyric and pegmatitic bodies are closely related to the syenite. All the rocks have undergone regional metamorphism.

Rocks of the syenite group are massive to gneissic, locally mylonitic, and characteristically brecciated. The breccia consists of clasts ranging in size from microscopic up to several feet across, in a finely granulated matrix cemented by brown carbonate. Fractures contain both brown carbonate and lavender- to bluish-opalescent silica. Cataclasis and deep weathering have resulted in nearly complete disintegration in most outcrops, so that good hand specimens are difficult to collect.

Interlayering of feldspar and mafic minerals occurs locally. At the top, individual layers exhibit nearly pure feldspar aggregates of potash feldspar, and more or less plagioclase; and at the bottom, higher proportions of hornblende, biotite, and black oxides. Such layers are discontinuous, and they rarely exceed a foot in thickness.

Relations to gneiss.—The syenite shows mainly gradational relationships to gneiss. Near the gneiss it is more gneissic, and locally mylonitic, with alternating layers of syenite and lenses of blue quartz. At the Red Rover Mine, the syenite contains lenticular bodies of amphibolite which appear to be inclusions of mafic gneiss.

Locally, within the gneiss, there are lenticular bodies of dark syenite rock of as much as five feet in thickness, with ill-defined contacts. Contact zones between syenite and gneiss, north of Acton and northwest of Vincent, are extremely complex and probably reflect intermittent periods of differentiation and autointrusion of syenitic magma, presumably also the replacement of gneiss by syenite. Irregular, fine-grained dark syenitic bodies are in sharp contact with gneissic coarser-grained leucosyenite, but they show gradational contacts with coarse-grained mafic syenite. Still later dikelike bodies of blue-quartz-bearing syenite, granite, and alkali granite cut both the mafic phases and the gneissic leucosyenite. Dark dikes of monzonitic composition, apparently stemming from the syenite group, transect the gneiss. All phases of the syenite, including adjacent gneiss, are intruded by tabular bodies of blue-quartz granophyre and pegmatite, which show both sharp and gradational contacts. Tabular bodies of the granophyre occur parallel to foliation, in both gneissic syenite and gneiss.

Relations to gabbro and diorite.—No well-exposed contacts between the syenite and the anorthosite groups were observed in the western San Gabriel Mountains. As far as is known, the syenite is peripheral to the anorthosite mass. This spatial relationship, and the occurrence of phases intermediate between gabbro and syenite, suggest that the syenite and the anorthosite groups are closely associated in time, the syenite being somewhat younger in the sequence. Monzonitic and dioritic phases of the syenite are cut by the leucosyenite and quartz-bearing syenite. Blue-quartz granophyre and pegmatite like those found in the syenite also cut the diorite of the anorthosite group.

Basic dikes cut the syenite, but these may be younger than the dikes that cut the anorthosite group. Mesozoic (?) alaskite (leucogranite) dikes and masses intrude the syenite and cross-cut the blue-quartz granophyre and pegmatite.

PETROGRAPHY

Syenite, Quartz-Bearing Syenite, Blue-Quartz Granite, et cetera

Rocks of this group are commonly medium-grained, xenomorphic- to hypautomorphic-granular, and they weather light to dark brown. On fresh surfaces, the potash feldspar is buff to yellow, but rarely greenish or bluish except where the ferromagnesian content of the rock is high. Quartz, where present, is blue or grayish-blue.

In the gneissic syenite there is parallel alignment of ferromagnesian clots, and the fabrics are granoblastic. Sparsely scattered mafic clots give a spotted appearance to some leucosyenite. Weathered-out biotite clots give dioritic phases a pitted surface.

Cataclasis has resulted in numerous irregular microbreccia zones, especially in the quartz-rich phases of massive rocks. Such zones, only a few millimeters wide, contain randomly oriented angular fragments of quartz and feldspar in a carbonate cement.

There is considerable variation in the relative amounts of the constituent minerals in rocks of the syenite group. Typical syenite contains about 50 per cent microperthite, 5 per cent microcline or orthoclase, 20 per cent oligoclase, 15 per cent biotite, 5 per cent ilmenite or magnetite, and the remainder hornblende, augite (relicts), quartz, apatite, epidote, zircon, sphene, and later chlorite, fine-grained white mica, and carbonate. The quartz-bearing syenite, blue-quartz granite, and alkali granite contain from 5 to 40 per cent bluish quartz. In the monzonitic and dioritic phases, plagioclase forms up to 45 per cent, and in general there is also an increase in hornblende over biotite.

Potash feldspars.—The potash feldspar grains are anhedral and consist mainly of microperthite (pls. 4, *b*; 5, *b*; 6, *b*) and subordinate microcline with grid twinning. Orthoclase is rare, in most thin sections.

Replacement-type microperthite, in which twinned oligoclase is embayed and veined by irregular bodies of orthoclase or microcline, is subordinate in those specimens examined. The typical microperthite is of the exsolution type, in which closely spaced and parallel blades, and spindle-shaped bodies (less than 0.01 millimeters thick) of oligosclase (An_{20}) occur in a host of microcline, but rarely orthoclase. The blebs of oligoclase, in most grains, are oriented parallel to (100). The proportion of oligoclase to potash feldspar is about 50:50 per cent, although in some of the very fine, almost submicroscopic perthite, oligoclase blebs are widely spaced and form only about 10 per cent of a whole grain. Throughout the specimens examined, however, the exsolution-type microperthite is surprisingly uniform in appearance. The microperthite and other potash feldspars are mostly unaltered, with only a few inclusions of white mica. Some of the grains have inclusions of rutile needles parallel to (001) or (010) cleavages.

Plagioclase.—Oligoclase (An_{15-25}) occurs as well-twinned subidiomorphic grains, many of which show irregular embayments or nearly complete replacement by microcline. In the monzonitic rocks, most of the oligoclase grains, as well as many of microperthite, are surrounded by sharply defined rims of albite. The oligoclase is partially or completely saussuritized and is clouded with fine-grained white mica; its appearance is in contrast to the fresh look of the microperthite.

Quartz.—The bluish quartz is typically anhedral and has pronounced undulatory extinction. In the quartz-bearing syenite, blue-quartz granite, and alkali granite, bluish quartz is commonly found as globular grains and irregular mosaic aggregates which penetrate feldspar. Numerous small isolated bodies of quartz produce a sieve texture, in some feldspar grains. In places, fine-grained myrmekitic quartz is intergrown with oligoclase.

Most of the quartz contains trains of dusty inclusions and scattered needles of rutile. These probably scatter light to give bluish colors to the quartz, as seen in hand specimen. Mosaics of fine-grained quartz are intergrown with black oxides, epidote, and other secondary minerals, within mafic clots. Clear quartz intermixed with albite occurs as rims around many grains of microperthite.

Ferromagnesian minerals.—Metamorphism, and probably other alteration processes as well, has resulted in the breakdown of most of the primary ferromagnesian minerals into aggregates of any (or in some cases all) of the following minerals: hornblende, biotite, black oxides, and varying amounts of intergrown epidote, quartz, talc, chlorite, leucoxene, and carbonate.

Most of the original ferromagnesian mineral was a pyroxene, probably augite, as indicated by:

1. Relicts of clear augite in the cores of some mafic clots.
2. Subrectangular outlines of many mafic clots; in some slides, the form of typical cross sections of augite is preserved.
3. Mutually parallel arrangement of hornblende prisms and biotite flakes, in the margins of mafic clots. This suggests control by prismatic cleavage, such as that of a pyroxene. Tiny grains of black oxides and other secondary minerals, in the cores of some clots, are arranged in a square grid pattern, as though controlled by the (110) cleavage of a pyroxene.

In the dark syenite, many of the mafic aggregates are oval in outline and consist essentially of a mixture of fine-grained black oxides and talc. Possibly such clots represent former olivine.

Augite.—Relatively fresh anhedral relicts of augite ($z \wedge c = 40°$) were found in the cores of a few mafic aggregates. Some relicts have a schiller structure of included parallel bars of black oxides.

Hornblende.—Commonly, the hornblende is fine-grained and fibrous with $x =$ yellow, $y =$ dark green, and $z =$ dark blue-green, or green. It occurs mainly as uralitic fringes around mafic clots. In some thin sections, pseudomorphs, probably after augite, are characterized by a rim of blue-green hornblende and a core of fine-grained pale-brown cummingtonite needles. The shapes of some mafic clots suggest a possible original aggregate of three or four pyroxene crystals. The whole aggregate is fringed by fine-grained fibrous hornblende elongate, perpendicular to the rim. The interior consists of a fine-grained intergrowth of black oxides, talc, chlorite, quartz, and an occasional pyroxene relict. The fibrous hornblende, in some sections, fills fractures in surrounding feldspar.

Biotite.—The biotite ($x =$ golden yellow, $y + z =$ dark green) is fine-grained and occurs in aggregates of randomly oriented flakes surrounding irregular grains of black oxides. In some mafic clots, biotite flakes have a parallel arrangement; in others, scattered flakes are disposed in a radial pattern. Biotite flakes generally occur peripheral to hornblende fringes, and where both minerals are present the flakes grow parallel to hornblende prisms. Biotite flakes also grow parallel to lamellae in microperthite, and evidently they replace potash feldspar.

Accessory minerals.—Black oxides are ilmenite or titaniferous magnetite in part altered to leucoxene or hematite. They occur as anhedral grains and as veins, also surrounding many feldspar grains. Fine-grained black oxides intermixed with secondary minerals, in the mafic clots, probably result from the breakdown of original ferromagnesian minerals.

Subhedral apatite crystals are abundant, especially as inclusions in mafic clots. Sphene is found occasionally as euhedral wedge-shaped grains close to, or within, mafic clots, also as rims around individual grains of black oxides. A few roundish crystals of zircon occur in most sections.

Alteration minerals.—Fine-grained epidote and white mica are the main alteration products of oligoclase. Aggregates of fine-grained granular epidote occur intermixed with other secondary minerals, in the cores of some mafic clots, and also form rims around aggregates of biotite, black oxides, and quartz. Medium-grained poikiloblastic epidote, probably metamorphic in origin, occurs in the monzonitic and dioritic rocks.

Pale-green chlorite replaces part of the biotite. Carbonate and quartz occur mainly in veinlets, although some granular carbonate, intermixed with fine-grained quartz, forms discontinuous borders to many biotite aggregates.

Blue-Quartz Granophyre and Pegmatite

The syenite and adjacent gneiss contain lenticular segregations and dikelike bodies of white to pink weathering, fine- to coarse-grained pegmatitic rock which is distinguished by granophyric, graphic, and irregular intergrowths of bluish quartz and microperthitic alkali feldspar. The bodies range in size from a few inches up to four feet in width. Some contain a core of nearly pure quartz and are foliated parallel to the walls, due to discontinuous quartz concentrations or, rarely, by aligned ferromagnesian minerals.

The blue-quartz granophyre and pegmatite are older than the alaskite bodies, for they are cut by them. They are probably related to the syenite genetically, because of close spatial relationships and similarities in mineralogy and textures. Contacts with syenite are generally sharp, but gradational relationships are also present.

The rocks consist of about 10 to 25 per cent plagioclase, 35 to 50 per cent microperthite, and 40 per cent quartz. In the specimens examined, biotite, hornblende, and black oxides formed less than 5 per cent of the rocks. A few flakes of muscovite were observed in some sections, as well as an occasional euhedral apatite or slightly rounded zircon crystal.

Microperthite.—Microperthite grains are anhedral and similar to those of the syenite. Both exsolution and replacement types occur. Many grains of the exsolution type differ from those of the syenite in that some potash feldspar hosts contain only very sparsely scattered blebs of oligoclase. Such blebs are oval, in cross-section, and are oriented parallel to one another within each grain. The replacement perthite shows very irregular, patchy embayments and penetrations of plagioclase by microcline, and some grains of the exsolution type of microperthite contain subrectangular relicts of oligoclase, with common optic orientation. The plagioclase of the microperthite, oligoclase (about An_{20}), is partially clouded with fine-grained white mica and is saussuritized, in the replacement type, but is clear in the exsolution type. Commonly, the potash feldspar is fresh. Many grains have rims of clear quartz or albite. Some grains are large enough, with respect to the grain size of surrounding minerals, to be called phenocrysts.

Plagioclase.—Plagioclase also occurs as subidiomorphic grains of albite-oligoclase (An_{10-20}) with normal zoning, much of which is clouded with fine-grained white mica and is saussuritized.

Quartz.—Under the microscope, the bluish quartz grains are characterized by irregular shapes and strong undulatory extinction. Most grains contain dusty inclusions, and intergrowths of quartz and feldspar are complex. Quartz grains or aggregates of grains are globular, ameboid, and they embay or poikilitically penetrate feldspars. Individual grains of feldspar commonly contain numerous isolated clusters of quartz blebs which are probably cross-sections of intergrown quartz rods. Quartz bodies, in the feldspars of pegmatitic rocks, tend to have roughly triangular shapes and result in graphic textures. Myrmekitic quartz is common in all of the rocks, but it occurs mainly within feldspars close to the edge of grains.

Larger grains of feldspar, in the fine- to medium-grained granophyric rocks, are surrounded by finer-grained intergrowths of quartz and feldspar. In some specimens, the intergrowths result in centric or spherulitic texture.

Aggregates of quartz tend to be lenticular and to be elongated parallel to foliation. Many of the quartz-rich rocks appears mylonitic, and some specimens contain irregular microbreccia zones which consist of tiny angular fragments of quartz and feldspar cemented by silica of low refractive index (pls. 7, *b*; 8, *b*).

Alteration products.—A few scattered flakes of bright green chlorite, formed after both hornblende and biotite, were observed. Hematite and leucoxene replace much of the black oxides. Fine-grained white mica and epidote minerals are mainly alteration products of plagioclase. Carbonate and late quartz occur in veinlets.

ORIGIN AND HISTORY

A genetic relationship between the syenite and the anorthosite group seems probable because of (1) spatial relationships: the syenite occurs in the periphery of the anorthosite mass, and as far as is known, rocks of this distinctive type are found nowhere else in the Transverse Ranges, San Gabriel, or San Bernardino mountains; (2) the presence of rocks intermediate in composition between syenite and the anorthosite groups, such as monzonites. Rocks of the syenite group, though somewhat younger than those of the anorthosite group, probably belong to the same general period of intrusion. Syenite of this type is closely associated with anorthositic rocks in other parts of the world (Buddington, 1939; Eskola, 1952). A possible co-magmatic sequence of rocks for this association is: gabbro–diorite–anorthosite–monzonite–syenite–quartz-bearing syenite–alkali granite–blue-quartz granophyre and pegmatite. Mafic bodies are associated with both the anorthosite and the syenite; primarily, basic dikes follow the anorthositic mafic bodies. Later differentiates in the sequence suggest enrichment in K_2O, SiO_2 and FeO.

Although the writers prefer a magmatic origin for the syenite group, there is also the possibility that the syenite is an "ultrametamorphic" rock similar to rocks in the granulite facies of regional metamorphism. Such a rock might originate by partial fusion of gneiss at depth, or possibly from a reaction between gneiss and a hot intrusion of rocks of the anorthosite group. Features suggesting this are: (1) abundance of gradational relations between syenite and gneiss, (2) similar blue-quartz and replacement-type microperthite, in both syenite and gneiss. Syenitic magma originating in such a way could reintrude both gneiss and the anorthosite group, and at the same time develop by differentiation to produce features such as layering by crystal settling and silica-rich end products such as blue-quartz granophyre and pegmatite. In many respects, the syenite group resembles charnockite. A resolution of this problem of origin will have to await studies by future workers.

Origin of Microperthites.—The two distinct types of microperthite in the syenite and related rocks probably have different origins:

1. That one type probably originated by the unmixing of a magmatic alkali feldspar is suggested by its uniformity in appearance and composition throughout the syenite. The oligoclase blades are generally of constant width, are uniformly spaced, and have a nearly constant ratio of 50:50 per cent, with respect to the potash feldspar in any grain. These relations seem difficult to explain by metasomatism. The unmixing of oligoclase from an original magmatic alkali feldspar would probably require rather slow cooling conditions. That this unmixing took place during slowly falling temperatures, after regional metamorphism, is also a possibility. Shearing stresses accompanying metamorphism might have had an activating effect on the unmixing processes. Similar perthites are described from metamorphic rocks by Eskola (1952) as "hair-perthite" in the granulite of Lapland.
2. A second type probably originated by replacement of earlier formed oligoclase by potash feldspar. The patchy character of the intergrowths and the general lack of a constant ratio between the potash feldspar and oligoclase in any grain suggest this.

The replacement microperthites are probably products of late magmatic action. A residual liquid enriched in SiO_2 and alkalies, mainly K_2O, would react with earlier formed minerals such as oligoclase. Quartz and albite rims around the exsolution-type microperthite grains, as well as granophyric and other complex intergrowths of blue quartz and feldspar, were probably also formed during this stage.

It is possible also that the replacement-type microperthites are related to regional metamorphism and metasomatism, because similar microperthites occur in the gneiss. Field and petrographic evidence to date are inconclusive in this regard.

Metamorphism.—The syenite has undergone at least one period of regional metamorphism, probably in association with the emplacement of nearby Mesozoic (?) intrusive rocks. The metamorphism is indicated by gneissic layering and granoblastic textures. Local mylonitic and cataclastic zones are conspicuous in the gneissic parts of the syenite and are much older than shears and minor fault zones throughout the mass. Several mineral changes, such as the alteration of pyroxene and olivine to hornblende, biotite, and other products, are interpreted as metamorphic, although they may be the result of late magmatic processes.

According to this interpretation, the syenite has probably attained at least the amphibolite facies of regional metamorphism, except for the effects of regressive metamorphism and hydrothermal alteration. The essential mineral assemblage of the syenite; biotite–hornblende–microperthite–oligoclase–quartz, would be stable in the amphibolite facies. Minerals such as hornblende, microperthite, and oligoclase would tend to be unstable in lower grades of metamorphism. The formation of fibrous biotite, chlorite, sericite, and epidote may result from regressive effects, although it is quite possible that they are late magmatic or hydrothermal in origin.

LATER QUARTZ-BEARING ROCKS AND MIGMATITES

Numerous granitic dikes and bodies, which range in width from a few inches up to many feet, intrude both gneiss and the anorthosite–syenite complex. These intrusions apparently stem from the larger Mesozoic(?) plutonic masses, although probably there is more than one age of intrusion. Complex networks of such dikes occur in the gneiss within large areas of anorthosite (map 2, *a* and *gr*). In such areas, mixed rocks or migmatites have developed, in which ptygmatically folded and boudinaged aplitic and pegmatitic injections are conspicuous.

The granitic rocks are fine- to medium-grained or pegmatitic, and are pink, white, or buff in color. The fine- to medium-grained rocks are commonly aplitic or hypautomorphic-granular in texture. Some are strongly granulated and sheared. In composition, they vary from granite to quartz diorite. A typical composition is 40 per cent potash feldspar (mainly microcline with minor orthoclase and microperthite), 20 per cent oligoclase, 30 per cent quartz (plus more or less granophyre and myrmekite), less than one per cent biotite, about one per cent zircon and apatite, and traces of black oxides. A little sericite and fine-grained epidote cloud the plagioclase.

The quartz-bearing dike rocks are apparently related to the Mesozoic(?) plutons which surround the anorthosite-syenite complex. These include diorite, quartz diorite, granodiorite, quartz monzonite, and granite (Jahns & Muehlberger, 1954; Oakeshott, 1954; Dibblee, 1960, 1961). Except for Tertiary dikes and hypabyssal intrusions, these rocks are the latest intrusives in the area. Granitic injections in the migmatitic gneiss are probably also related to emplacement of Mesozoic (?) batholiths. Such injections, however, are generally older than the dikes, and in part may be derived from earlier periods of migmatization.

In some places, the rocks have undergone partial mylonization and minor deformation, and have been mildly metamorphosed.

OTHER ROCKS

In the San Gabriel Mountains and Soledad region, the granitic rocks are in turn cut by several kinds of dikes. Quartz diorite in Soledad Canyon, for example, is transected by dark lamprophyric dikes up to several feet thick. Basaltic and diabasic dikes are rare but are widespread in distribution; several have been noted northwest of Vincent, where they are easily confused with older basic dikes. Many of these may be younger intrusions related to Miocene volcanism.

EXPOSURES OF SIMILAR ROCKS IN SOUTHERN CALIFORNIA

Although true anorthosite and syenite from areas in southern California other than the San Gabriel and Orocopia mountains are unknown, there are wide exposures of gabbro and diorite, some facies of which resemble facies of the Orocopia and San Gabriel rocks.

The most widely distributed gabbroic rock in southern California is the San Marcos gabbro, which occurs as irregular masses along the core of the southern California batholith in the Peninsular Ranges (fig. 1), west of the San Andreas and San Jacinto faults, and west of the Orocopia exposures. The outcrop of the San Marcos gabbro nearest the Orocopia Mountains lies 58 miles to the west-southwest, near the Elsinore fault. According to Larsen (1948, p. 42), "No bodies of the San Marcos gabbro are known in the eastern part of the [Peninsular Ranges], as far east as the Colorado Desert."

The San Marcos gabbro, named and described by F. S. Miller (1937), includes rocks with a wide range of composition and texture but with nearly complete gradations between types. Exposures, although distantly separated, possess close genetic relationship because "they have similarity in character of outcrops and local structural features; similar relations to other rocks of the batholith, particularly with regard to age; susceptibility of all the hornblende-free rocks to similar local or widespread enrichment in hornblende; noteworthy similarities in mineralogy; and systematic changes in mineral content and chemiecal composition throughout the rocks of the group" (Miller, F. S., 1937, p. 1399). The most abundant rock type is a medium-grained dark-gray norite which locally grades into hypersthene gabbro. Associated hornblende-poor rocks are olivine norite, olivine gabbro, and more rarely hypersthene gabbro and norite carrying small amounts of quartz and biotite. Nearly equal in areal extent to these rocks are several types of hornblende gabbro. Anorthosite occurs on a very local scale; the name is applicable only to small segregations and hand specimens, rather than to mappable units (Miller, F. S., 1937, p. 1403). It is not necessary here to describe fully the petrography and mineralogy of these rocks because several workers have dealt with them previously in detail (Miller, F. S., 1937, 1938; Larsen, 1948, pp. 41–53; Miller, W. J., 1935, 1946; Hudson, 1922; Merriam, 1946, 1958; Creasey, 1946; Everhart, 1951).

It is quite unlikely that the San Marcos gabbro is related to the Orocopia or San Gabriel rocks for the following reasons: The gabbro is clearly part of the southern California batholith and was emplaced during the Cretaceous, probably early Late Cretaceous (Larsen, 1954); the gabbro cross-cuts and intrudes older sedimentary rocks that are now of the greenschist facies (Jahns, 1954, p. 37) and not of the amphibolite or granulite facies; the plagioclase of the gabbro and associates is universally calcic, averaging between An_{55} and An_{65}, and only very rarely is it as sodic as the feldspar of the Orocopia Mountains, which averages between An_{20} and An_{45}. The abundance of olivine, the lack of iron ores and apatite, and the paucity of potash feldspar are other significant differences. No syenite has been reported.

Diorite and gabbro are exposed a few miles to the northwest of Valyermo (figs.

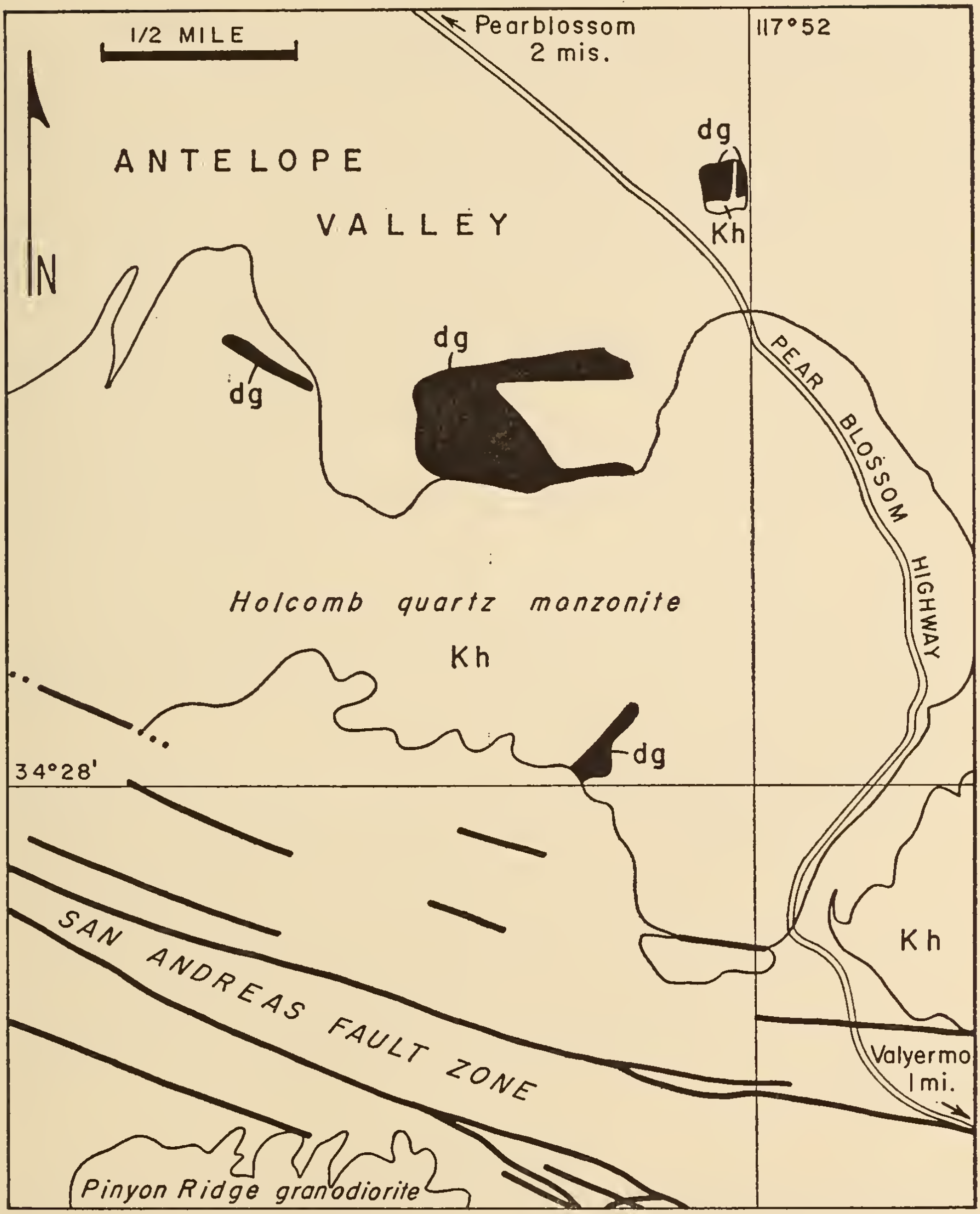

Fig. 4. Sketch geologic map showing location of diorite and gabbro exposures in Valyermo Quadrangle (fig. 1). Geology is simplified from Noble (1954). Key: Kh = Holcomb quartz monzonite; dg = diorite and gabbro.

1 and 4), on the northern flank of the San Gabriel Mountains (Miller, W. J., 1946, p. 466; Noble, 1954*a*). These are dark gray, fine- to coarse-grained rocks with segregations of coarse pegmatite consisting primarily of hornblende and plagioclase. Texturally and mineralogically, they closely resemble rocks of the same facies in the anorthosite complex of the San Gabriel Mountains, about 12 miles to the west.

They are therefore considered here, tentatively, as roof pendants of these older rocks, within the Holcomb quartz monzonite (Noble, 1954*a*).

As shown on figures 1 and 4, these bodies of diorite and gabbro lie to the north of the active strand of the San Andreas. Their position may therefore be anomalous with respect to the hypothesis of great separation on the fault between the San Gabriel and Orocopia mountains, and additional work along the fault zone may cause the idea to be abandoned. On the other hand, it is quite possible that they lie within a slice of the fault zone, inasmuch as it is thought that several faults lie beneath the alluvium of Antelope Valley. Perhaps these faults are parallel to the San Andreas fault and are a part of the system. They may be continuations of those branching from the principal active part of the San Andreas shown on maps to the northwest and southeast, and depicted here on figure 1 (Wallace, 1949; Dibblee, 1960*a*; 1960, pl. 7; 1961). If the Valyermo exposures are eventually assigned to a fault slice, it is possible that the slice has been displaced from the Tejon Pass region. In pre-Oligocene time the Tejon, Soledad, and Orocopia regions may have been joined in an east-west trending terrane, as discussed by Crowell (1960; 1962). We will have to await future studies of the whole region along the fault zone shown in figure 1 before this problem can be resolved.

Small exposures of gabbro and diorite occur near the San Andreas fault, two and three miles east of the Valyermo Quadrangle, in Grandview Canyon, and among a series of small limestone quarries. These rocks are quite unlike those of the anorthosite group and are clearly local amphibolitic pods associated with skarn and marble within quartz monzonite.

According to Dibblee (1954, p. 21) hornblende-rich diorite, with facies of quartz diorite and gabbro, are the dominant intrusive rocks of the low mountains within the Imperial Valley region and the eastern foothills of the Santa Rosa Mountains. The nearest spurs of this range lie directly across the San Andreas zone from the Orocopia Mountains, about 23 miles to the southwest. Although the Santa Rosa Mountains have not as yet been mapped geologically, except in gross reconnaissance, the rocks have been examined in the field for this study. The diorite and gabbro are coarse amphibolite in close association with marble and skarn that have been formed from calcareous sediments during intrusion of quartz diorite. They are genetically dissimilar to the Orocopia exposures and resemble them only superficially.

DISCUSSION

It now remains to compare the terranes in the Orocopia and San Gabriel mountains. Does the field and petrographic evidence indicate that the two masses could have been parts of the same complex, in the geologic past? Note that the photomicrographs, plates 3 to 8, are arranged with similar views shown together for comparison.

The gneisses in both areas occur as incomplete septa in the midst of younger plutonic masses, and as small blocks, masses, and inclusions. They range from dark amphibolite to leucogneiss, with variable amounts of hornblende and biotite. Contacts are gradational, and the foliation is nearly always steep. The gneisses are polymetamorphic, having in both cases been metamorphosed before the emplacement of the anorthosite-syenite complex, during its intrusion, and again at about the time of intrusion of Mesozoic(?) rocks. Mylonitization and late retrogression and alteration are locally conspicuous. The gneisses of both areas are now in the amphibolite facies with the same mineral assemblages. Minor pyroxene in the San Gabriel rocks suggests that some of the gneiss borders on the granulite facies. Blue or violet quartz is conspicuous and abundant in both areas and occurs as globular and myrmekitic masses which embay feldspar and form mosaics with other minerals. Plagioclase is commonly clear and has a xenoblastic texture; it generally ranges between An_{10} and An_{30} in composition, although it is somewhat more calcic in the amphibolite. The potash feldspar is predominantly microcline with patch-type microperthite, but with perhaps more untwinned orthoclase in the Orocopia gneiss. The hornblendes have similar pleochroism and occur as subidioblastic prisms, some of which are poikilitic. Biotite displays similar pleochroism in both gneisses, and is usually altered to chlorite, although the abundance varies considerably. Minor accessories (red garnets, zircon, scattered iron ores, etc.) are very similar in occurrence and percentage, although more apatite was noted in the Orocopia rocks.

The anorthosite group in both regions consists of (1) gabbro and diorite, with rocks transitional to anorthosite and minor quartz dioritic and monzonitic segregations, (2) anorthosite, (3) mafic bodies, and (4) basic dikes. The relations to the gneisses are also apparently identical, as shown by septa and inclusions of gneiss within the anorthosite group, by dikes and irregular bodies of the latter rocks cutting the gneisses and migmatites, and by the dioritic injections which parallel the foliation in the gneiss. Internal structures, such as discontinuous foliation and the alignment of elongate minerals, is similar. In the San Gabriel Mountains, foliations and lineations usually dip steeply, parallel to the borders of the complex, but with unclear relationships in the Orocopia Mountains.

The principal rock types—the gabbro, diorite, and transition rock—are fine- to coarse-grained, and mottled greenish- and brownish-black. In both places they are characterized by large grain size. Hornblende crystals greater than a foot in length have been noted in the Orocopia diorite, and altered hypersthene crystals greater than 10 feet in the San Gabriels. The plagioclase crystals range up to 6 inches in diameter, in the Orocopias, and are commonly 2 to 6 inches in diameter in the San Gabriels. Textures are commonly hypautomorphic, but locally subophitic. The plagioclase of the Orocopia rocks ranges between An_{28} and An_{45}, with only one specimen containing An_{55-70}. In the San Gabriel area the typical plagioclase is An_{25-45}, although some of the darker marginal rocks contain An_{50-60}. In both areas the plagioclase is of two types: (1) medium- to coarse-grained, uniform in composition, and clouded with epidote and locally white mica; and (2) fine-grained, strongly zoned, with cores as calcic as An_{45}, and clear. The finer-grained andesine occurs interstitially as a granular mosaic or as fracture-fillings in the coarser-grained andesine (pl. 3). The ferromagnesian minerals of these rocks, however, show some differences. In the San Gabriel area, minor olivine occurs, but most of it has been altered to serpentine, talc, and iron oxides. In the Orocopias, none has been noted from these rocks, although mafic segregations contain ovoid aggregates of secondary intergrown fine-grained magnetite, serpentine, talc, and biotite suggestive of olivine. The former existence of primary pyroxene, in the Orocopia region, is now suggested only by biotite clusters that have rectangular or subrectangular outlines. In the San Gabriel rocks, on the other hand, both hypersthene and augite are present as minor relics in aggregates of secondary minerals, notably hornblende and biotite. The hornblende, which is the most abundant ferromagnesian mineral in the Orocopia anorthosite group, is quite similar in pleochroism and optical properties to that of the San Gabriel rocks. In both areas, similar varieties and habits were noted, however, and much of the hornblende is ragged and poikiloblastic, with many inclusions of plagioclase, sphene, iron oxides, and other minerals. The biotite from both areas has similar pleochroism and occurrence: as mantles around grains of black iron oxides and plagioclase; intergrown with hornblende; and as apparent replacement of pyroxene. The accessory minerals include ilmenite and titaniferous magnetite, as scattered fine grains and as veinlets, and as irregular masses which partially enclose other minerals. Apatite and sphene are ubiquitous, and zircon is fairly common in both regions.

The anorthosites of both areas are remarkably similar. Anorthosite is more widely exposed and coarser grained, in the San Gabriel Mountains, but in both areas it displays the same textural and structural features, including the pervading small fractures. Measurements of the plagioclase composition shows An_{20-45} for the Orocopia rocks and An_{25-45} for the San Gabriel rocks. Coarser and more altered crystals are transected by finer and clearer plagioclase.

The mafic bodies are also very similar, with complex igneous and metamorphic textures and fabrics. Although the mineralogy is diverse, in both areas aggregates of ilmenite and titaniferous magnetite, and high concentrations of apatite, are conspicuous. In the San Gabriel Mountains some mafic bodies have been mined for titanium, whereas in the Orocopias some of the larger have only been prospected. Basic dikes with similar shapes and structures are also associated with both complexes; their foliation and schistosity indicate metamorphism after emplacement, and the mineral assemblage hornblende-plagioclase shows that they have been brought to the amphibolite facies of regional metamorphism.

The syenites and related rocks of the Orocopia and San Gabriel mountains show very similar intrusive and gradational relations to the gneisses. Banded quartz-bearing syenites grade into blue-quartz gneisses. The syenites in both cases are massive to gneissic, highly fractured and brecciated, cemented with brown carbonate, and are locally mylonitic. Segregation layering, even rhythmic banding, in which the feldspar grades downward to an aggregate of dark minerals, occurs locally. In the Orocopia Mountains, where boundaries are much better exposed, the syenitic rocks are gradational with the gabbro and diorite. Hornblende diorite, with increasing quartz and potash feldspar, grades into quartz-bearing syenite through monzonitic and syenitic phases. These transitional phases have been recognized in the deeply weathered Soledad region. Here monzonitic and dioritic phases are common, and they are cut by leucosyenite and quartz-bearing syenite. Basic dikes, with metamorphic textures, intrude syenite as well as diorite. In both areas, Mesozoic(?) alaskite dikes cut across the syenite, blue-quartz granophyre, and blue-quartz pegmatite.

In both regions the syenites, quartz-bearing syenites, and related granites have xenomorphic- and hypautomorphic-granular textures, and they carry distinctive blue or violet quartz. The rocks are about half microperthite, of two types: a distinctive exsolution type consisting of closely spaced parallel blades and spindle-shaped bodies of oligoclase in microcline; and a replacement type, consisting of twinned oligoclase, embayed and veined by orthoclase or microcline. In the Orocopia rocks, a rimming of the microperthite by quartz or clear albite is perhaps more noticeable. The distinctive blue quartz is xenomorphic, with pronounced undulatory extinction and dusty inclusions of rutile in both terranes. It occurs as myrmekitic intergrowths and as globular grains which embay feldspars, locally resulting in sieve texture. Augite relicts occur in the San Gabriel syenite, but no original pyrogenic minerals have been recognized in the Orocopia syenite. The ferromagnesians are now aggregates of hornblende, biotite, oxides, and intergrowths of alteration products. The character of these aggregates, however, suggests original pyroxene and perhaps some olivine. The blue-quartz granophyres are quite distinctive rocks characterized by irregular and graphic intergrowths of quartz and feldspar, chiefly microperthite.

The San Gabriel and the Orocopia terranes are intruded by later quartz-bearing dike complexes, migmatitic zones, and irregular masses of alaskite. In composition, these range from quartz diorite through granite, but cross-cutting relationships indicate that there may be more than one age of intrusion. In both terranes, Tertiary volcanic dikes transect these rocks in turn.

SUMMARY AND CONCLUSIONS

In summary, the review of the last few paragraphs emphasizes that the two suites of rocks are remarkably similar. It seems improbable that two independent masses, 130 miles apart, could have had such complex and nearly identical geologic histories. The writers therefore conclude that the results of this field and petrographic study are largely consistent with the hypothesis that the two masses were at one time adjoining and part of the same terrane. Yet the Valyermo exposures of diorite and gabbro occupy an anomalous position, and there are other significant difficulties. It is aside from the purpose of this paper, however, to discuss at length the hypothesis of great strike slip, which is dealt with elsewhere (Crowell, 1962).

The dissimilarities between the rocks of the two regions may be largely accounted for by several factors. In the first place, the Orocopia rocks are contained in a narrow fault plate, underlain by a thrust, and the rocks are very much more deformed than those in the San Gabriel Mountains. Furthermore, there are far more dikes and bodies of younger granitic rocks and Tertiary volcanics in the Orocopias. These factors may account for the greater alteration of the Orocopia rocks, in which, for example, original olivine and pyroxene are apparently lacking. It seems likely also that the main core of the anorthosite mass is preserved in the San Gabriel Mountains and that only its outermost shells or extensions reached to the San Andreas fault. The Orocopia mass may therefore have been sliced off from the periphery of the complex, and so of course would not contain as high a percentage of anorthosite, nor such large crystals of plagioclase or hypersthene.

This investigation represents but the first stage in the study of the anorthosite-syenite complex in the two areas. Additional study of the rocks dealt with here is highly desirable, with an emphasis on petrogenesis and chemical material balance. The terranes should be mapped in as much detail as exposures allow, in order to refine our understanding of the shape or shapes of the intrusive masses. Data on ages are needed from isotopic measurements, but their interpretation will be difficult until the metamorphic history is thoroughly understood. It is essential, for example, to obtain radiometric ages for the anorthositic rocks in the Orocopia Mountains, for comparison with the ages now known for the San Gabriel rocks (Neuerburg and Gottfried, 1954; Silver *et al.*, 1960).

In conclusion, although the petrographic and field work described here may make the hypothesis of great strike slip on the San Andreas more acceptable, this work represents but one stage in an appraisal of the validity of that hypothesis. Other rocks in the two regions, as well as those exposed along the fault in between, need to be investigated in far more detail. Although this research is now underway (Crowell and Susuki, 1959; Crowell, 1960; 1962), the marshaling of evidence in support of or against the hypothesis will take many years and must await greater understanding of the geologic histories of the terranes involved.

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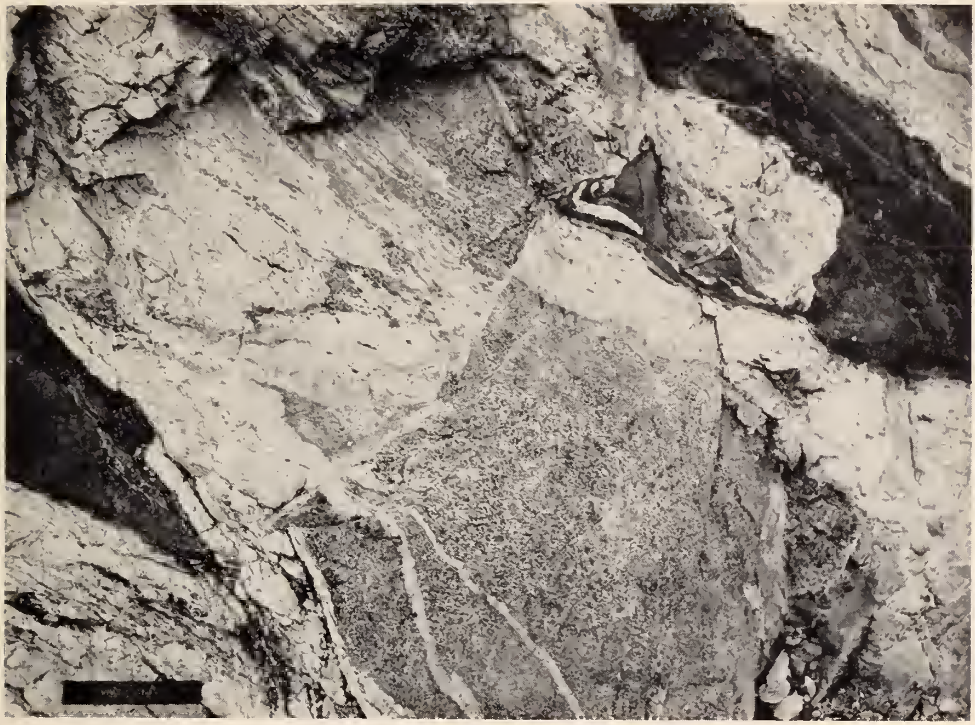
PLATES

PLATE 1

a. Blocks of gneiss intruded and surrounded by anorthosite with dark mafic bodies at left margin and in upper right. Painted Canyon, south wall, 1¼ mile up canyon from parking area. Photo locality 1, figure 2. Scale is 6 inches.

b. Dioritic gneiss cross-cut by aplitic dikes at top and bottom of photograph. The mottled dioritic texture is characteristic of border facies of the diorite and gabbro and has been emplaced within gneiss, the structure of which can be observed at the left. North flank of Orocopia Mountains. Photograph locality 2, map 2. Scale is 6 inches.



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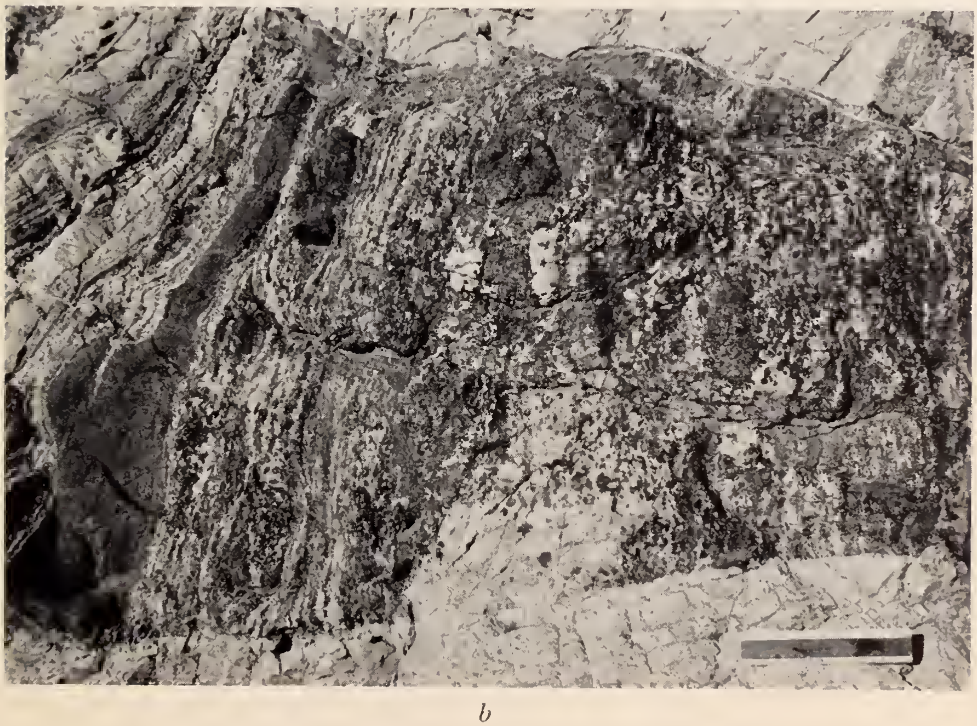


b

PLATE 2

a. Anorthosite in the eastern Orocopia Mountains. The white exposures are anorthosite and the dark are transition rock, diorite and gabbro, and mafic bodies. Looking northwest from photograph locality 3, map 2.

b. Anorthosite with mafic bodies in Painted Canyon. Note joints and minor faults. South wall of canyon 1¼ mile up canyon from parking area and ½ mile above dry waterfall. Photograph locality 1, figure 2. Scale is 3 feet.

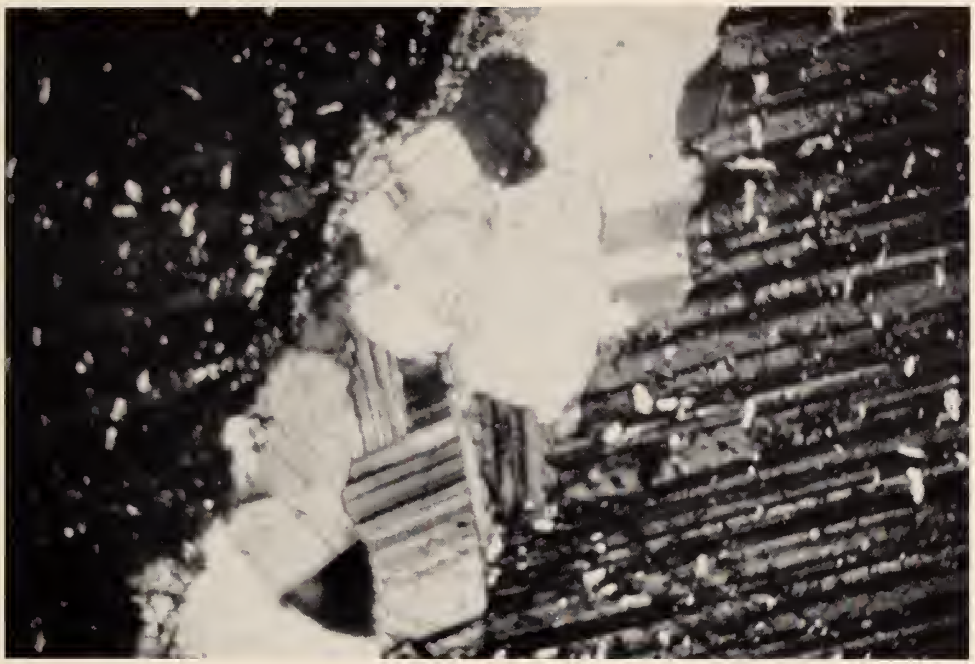
a

b

PLATE 3

Anorthosite (Veinlet of fine-grained andesine cutting across a large grain of plagioclase clouded with fine-grained epidote and sericite)

a. Orocopia Mountains, locality CWS 17; 1.4 mm across field.
b. San Gabriel Mountains, locality LG 1; 1.4 mm across field.



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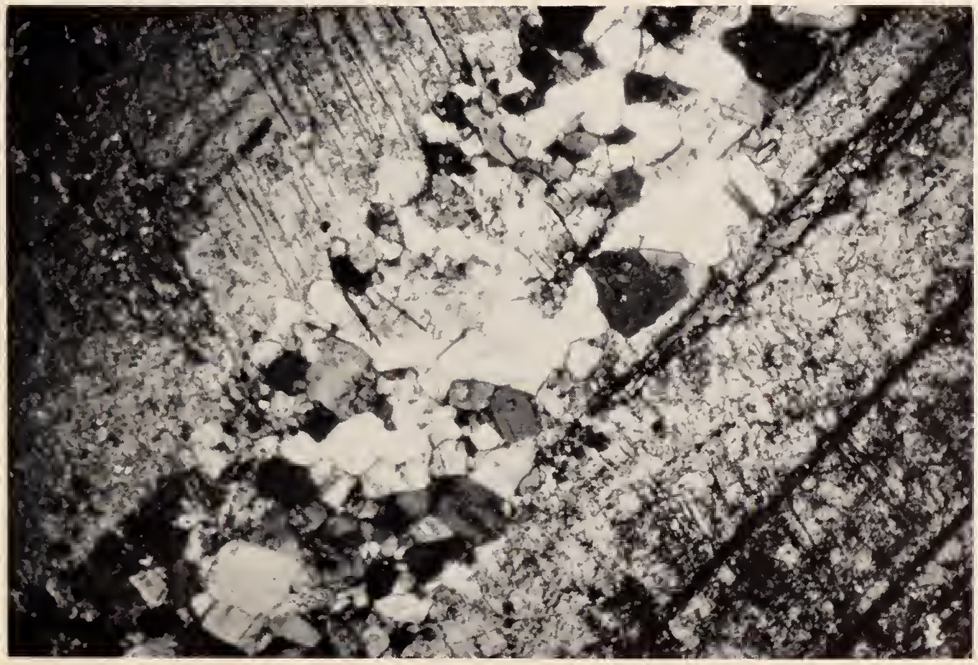


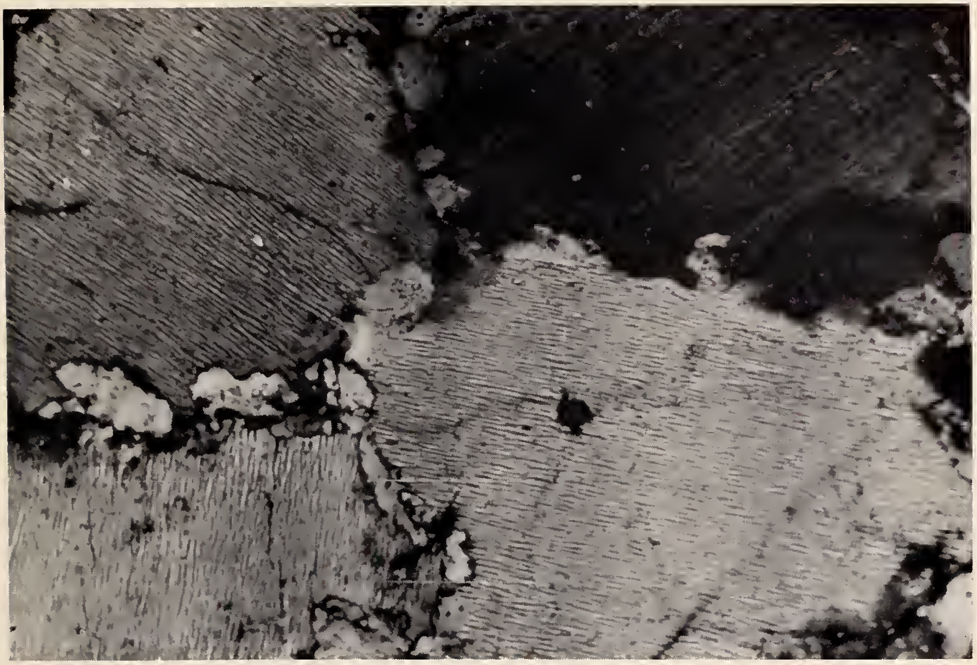
b

PLATE 4

Syenite (Typical hair microperthite showing uniformity of width and spacing of oligoclase blebs)

a. Orocopia Mountains, locality CW 102. Rims are clear potash feldspar and some qaurtz; 0.5 mm across field.

b. San Gabriel Mountains, locality PD 8–3. Interstitial grains are mostly clear quartz and rims are clear potash feldspar. 0.5 mm across field.



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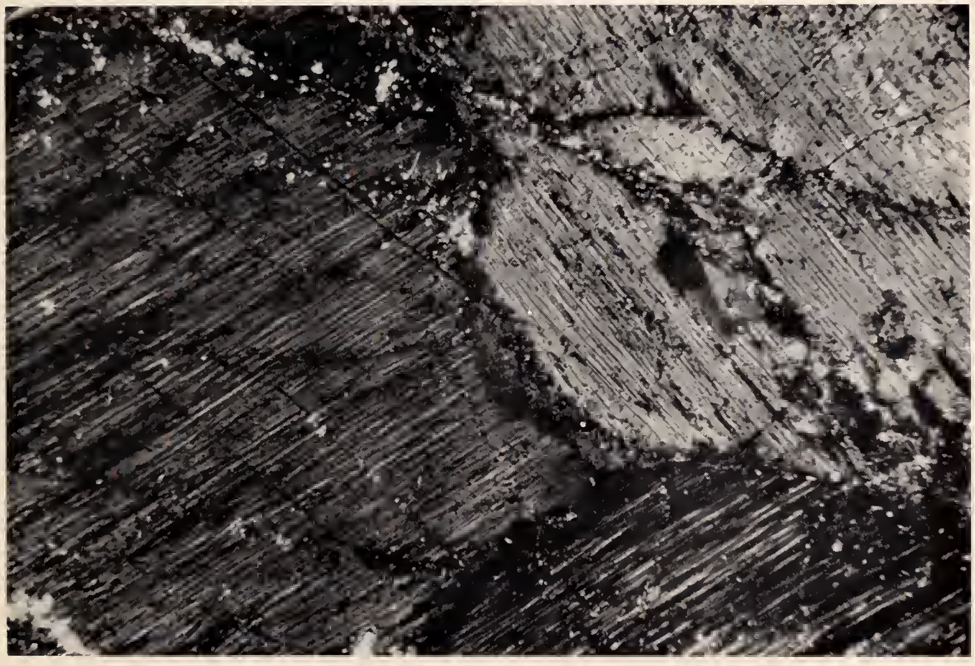
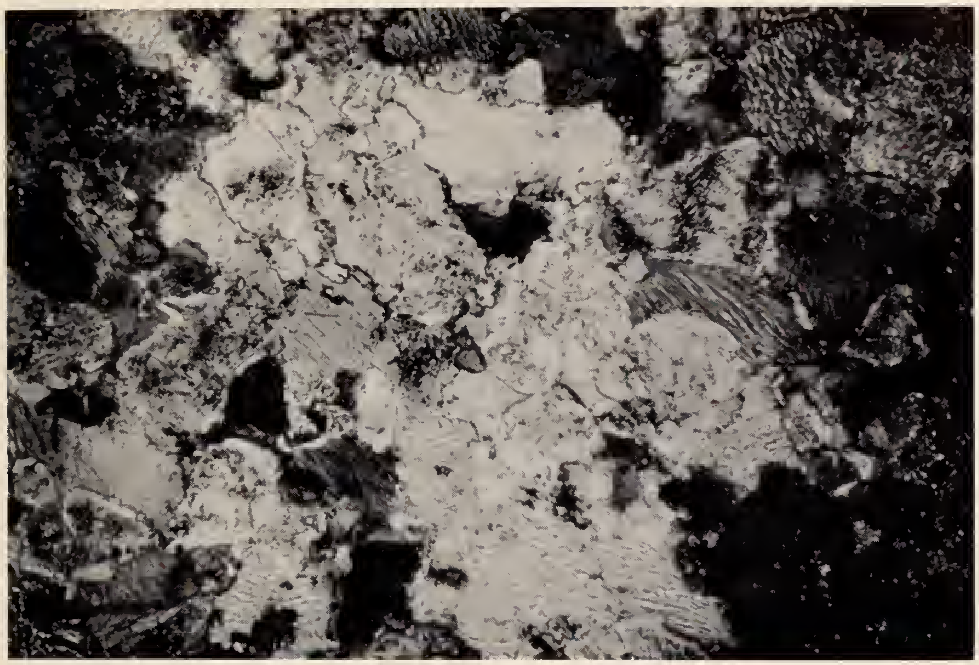


b

PLATE 5

Syenite (Note texture of feldspars)

a. Orocopia Mountains, locality CW104a; 1.4 mm across field.
b. San Gabriel Mountains, locality PD 9–3; 1.4 mm across field.



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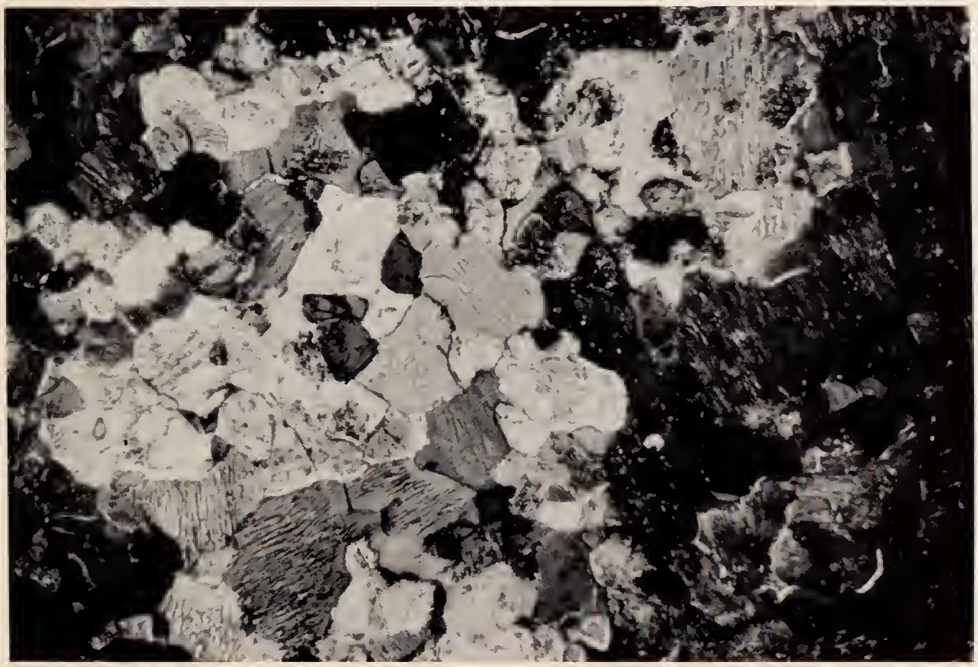


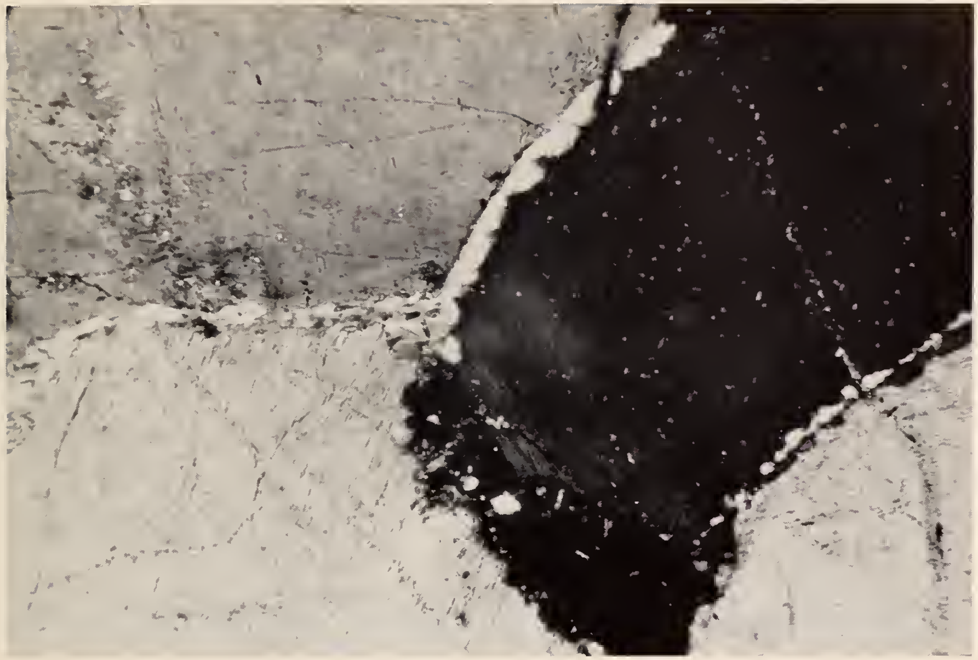
b

PLATE 6

Syenite (Note hairlike microperthite grains partially rimmed by clear quartz and albite)

a. Orocopia Mountains, locality CW 37d; 0.5 mm across field.

b. San Gabriel Mountains, locality PD 10–1; 0.5 mm across field.



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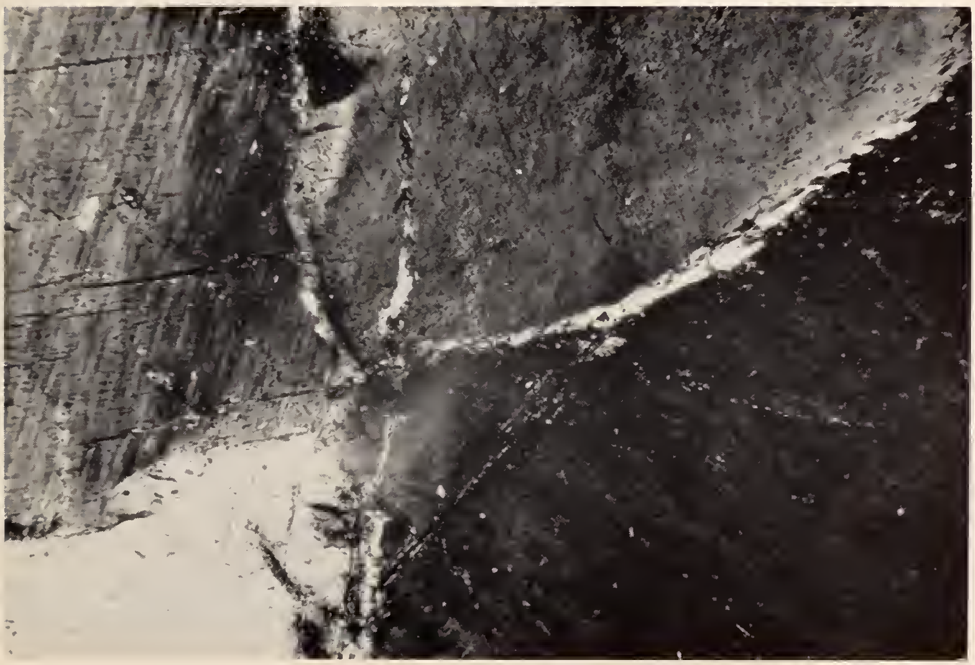


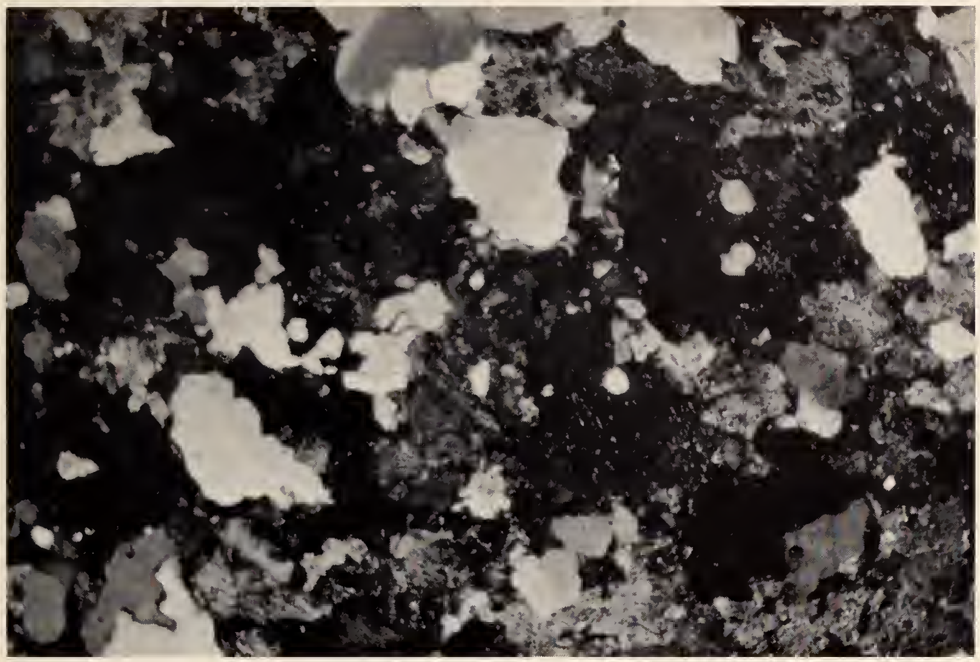
b

PLATE 7

Blue-quartz granophyre with globular quartz and microperthite intergrowths

a. Orocopia Mountains, locality CW 103b; 1.4 mm across field.

b. San Gabriel Mountains, locality PD 8a-3; 1.4 mm across field.



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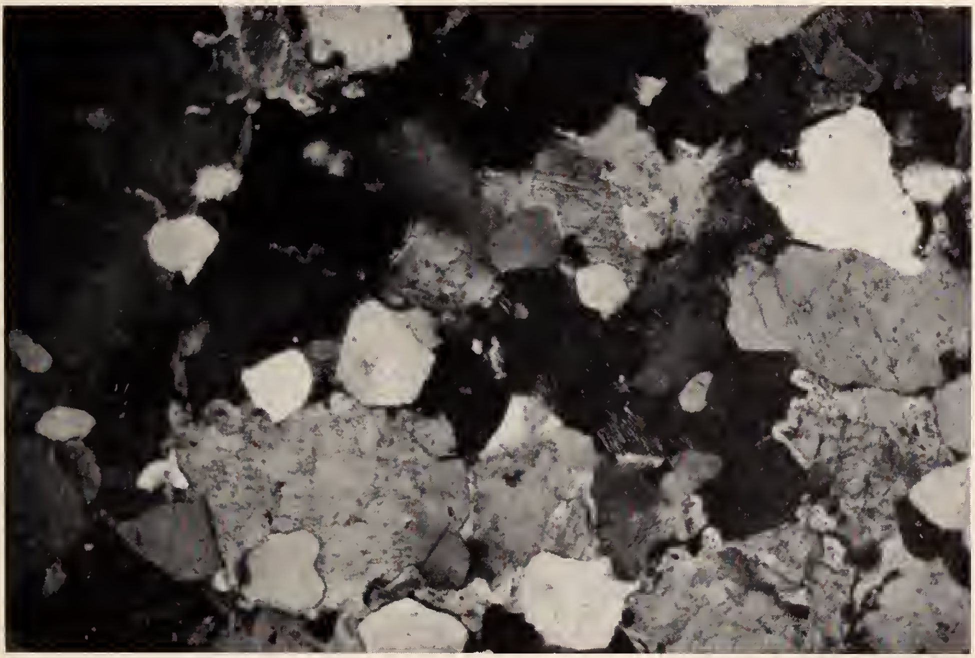


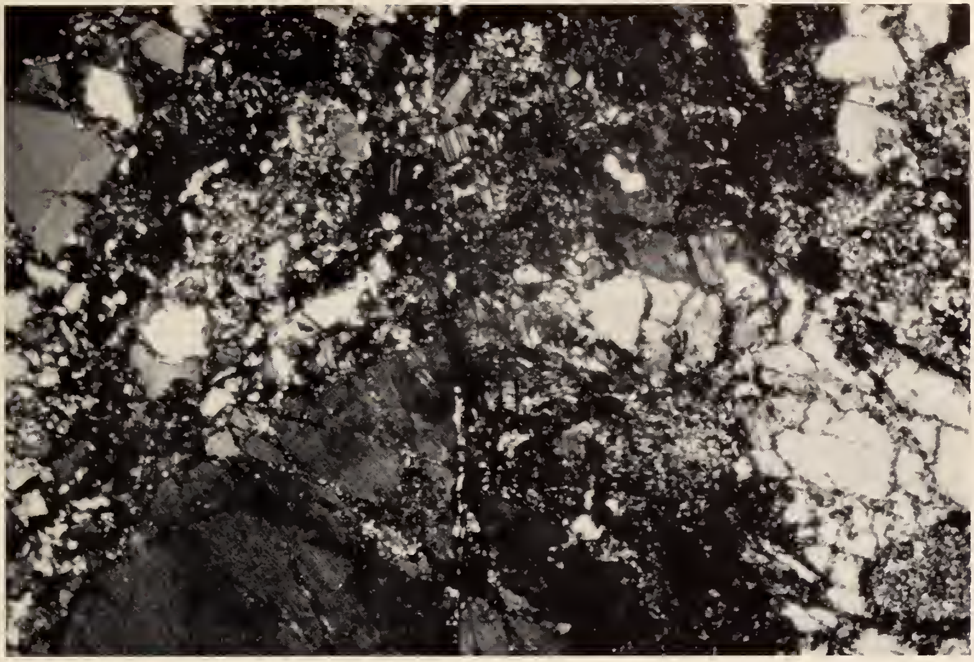
b

PLATE 8

Quartz-bearing syenite (Note microbreccia)

a. Orocopia Mountains, locality CW 103; 1.4 mm across field.

b. San Gabriel Mountains, locality RR 10b; 1.4 mm across field.



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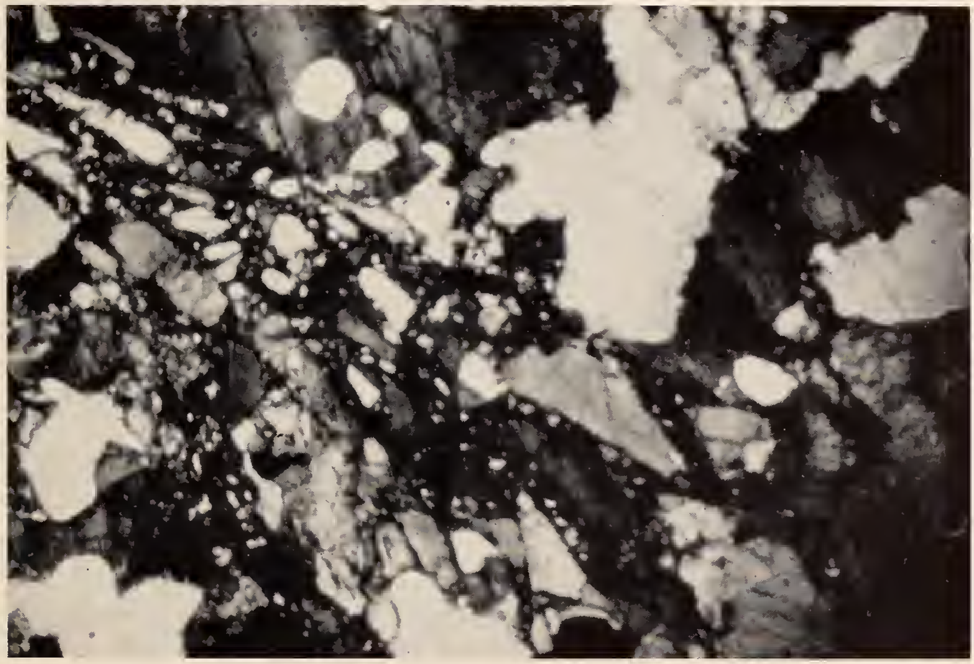

b

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